A New Version of Hydrometeor Videosonde for Cirrus Cloud Observations

By Narihiro Orikasa and Masataka Murakami

Meteorological Research Institute, Tsukuba, 305 Japan

(Manuscript received 27 January 1997, in revised form 18 August 1997)

Abstract

A new version of hydrometeor videosonde (HYVIS) has been developed to measure the vertical distribution of hydrometeors in cirrus clouds with low ice crystal concentrations. This sonde has two small video cameras that take pictures of particles from $7\text{ }\mu\text{m}$ to 5 mm in size, and transmits particle images by 1.6 GHz microwave to a ground station. The original HYVIS did not have enough sampling volume to evaluate the size distribution of hydrometeors in clouds with low number concentrations. To increase sampling volume, a small suction fan was added. From laboratory experiments, we have estimated the variation in sampling volume with changes of ambient air pressure and ascent velocity of the sonde. Theoretical calculation showed that the collection efficiency of the new HYVIS should be unity for all ice crystals larger than $10\text{ }\mu\text{m}$.

Some examples of cirrus cloud observations have demonstrated that the new HYVIS enabled us to determine reliable size distributions of ice crystals larger than $10\text{ }\mu\text{m}$ at 250 m intervals. The results of the new HYVIS measurements provide us with useful information about mechanisms for the formation and maintenance of cirrus clouds.

1. Introduction

High-level ice clouds are one of the most commonly occurring cloud types and cover about 20 % of the earth's surface (Barton, 1983). They are thought to strongly influence the global energy budget by modifying infrared radiation emitted from the earth's surface, and consequently, have a great impact on climatic change (*e.g.*, Liou, 1986). In order to understand the climate system, it is necessary to increase our knowledge about microphysical, radiative, and optical properties of cirrus clouds. *In situ* measurements on microphysical structures of cirrus clouds were made by using special, high-altitude flying aircraft. Therefore, limited studies have been made to date. Two-dimensional optical array probes, which are often used for aircraft measurements of cloud particles, do not have sufficient resolution to discriminate between cloud droplets and ice crystals whose sizes are smaller than about $100\text{ }\mu\text{m}$, and cannot detect details of crystal habits.

To overcome these difficulties, the cloud physics group in Meteorological Research Institute (M.R.I.) had developed balloonborne special sondes; a Cloud Particle Video Sonde (a prototype of Hydrometeor Videosonde) by Murakami *et al.* (1987) and a Hy-

drometeor Videosonde (HYVIS) by Murakami and Matsuo (1990). Earlier HYVIS cirrus cloud observations (Mizuno *et al.*, 1994) showed that sampling volume requires to be increased in cirrus clouds with low ice crystal concentrations. Moreover, the weakness of downward scattered light degraded the quality of particle images, making it necessary to change the illumination from natural light to artificial, controlled light. To meet these requirements, we have built a new version of the HYVIS. About 20 units of this new version have been launched in recent cirrus observations.

In this paper, we present details of the improvements in the new HYVIS and demonstrate its capabilities through a report of some observations.

2. Outline of the new hydrometeor videosonde

Figure 1 shows a photograph of the new HYVIS. Its weight is approximately 2.4 kg , which is about 1 kg heavier than the original HYVIS as a result of adding a suction fan and an associated battery. A cut-out view of the new HYVIS is shown in Fig. 2. The dimensions of the new HYVIS are $280\text{ mm} \times 106\text{ mm} \times 500\text{ mm}$, including the electric light for the microscope. It has two video cameras with different magnifications to take pictures of hydrometeors from $7\text{ }\mu\text{m}$ to 5 mm in size. Hydrom-

Fig. 1. Photograph of the new version of the HYVIS.

eteors are sucked through a particle inlet of 1 cm in diameter and collected on a surface of transparent 35 mm leader film over which silicone oil (KF96, Shin-Etsu Chemical Co.) is applied.

Two types of images are transmitted alternately with a period of about 10 seconds. For the first 6 s, the microscope camera takes pictures of ice crystals of the order of 10 to 100 μm in size. At the beginning of the shooting of the close-up camera, the film is moved at a distance between the two cameras. Then the close-up camera takes pictures of larger ice crystals of the order of 100 μm to 1 mm for another 4 s.

The ground receiving system for the new HYVIS is the same as for the original HYVIS. Images of hydrometeors taken by two small video cameras are transmitted by 1687 MHz microwave to a ground station in real time so that it does not need to be retrieved later. At the same time, meteorological data are transmitted at a frequency of 1673 MHz.

3. Description of the improvements

3.1 Addition of a suction fan

As shown in Fig. 2, the new HYVIS with a small suction fan (V484M, Micronel) forces hydrometeors to fall through the particle inlet (nozzle with a section area ratio 4:1 between the top and the base). The velocity of air flow under the condition of normal temperature and 1000 hPa is approximately 12 ms^{-1} at the base of the impactor nozzle, which corresponds to a flow rate of about 1 l s^{-1} , five times as voluminous as the rate of the original HYVIS (natural ventilation type). The addition of the fan makes the following devices necessary:

- Coating silicone oil on the sampling film to prevent ice crystals from bouncing off.
- Precise movement of the film from the sampling position (the position over the microscope camera) to the position over the close-up camera.

Fig. 2. Cut-out view of the new HYVIS.

- Monitoring changes in flow rates with environmental conditions.

Silicone oil is gradually released on to the film through leakage holes from a silicone oil reservoir, and is spread thinly and uniformly with the help of a wiper blade. Silicone oil is pushed out from the reservoir by expanding air in the reservoir as the HYVIS ascends and ambient pressure decreases; this is the same mechanism as that replica solution is released on to the film in the snow crystal sonde (Magono and Tazawa, 1966). Since the viscosity of silicone oil increases as the temperature decreases, silicone oil with low viscosity (*e.g.*, 20 cSt) is used.

Accuracy of film movement was improved by adopting a winding mechanism that controlled the rotation angle of the sprocket instead of the rotation time. It is confirmed that the accuracy of the distance was $35.6 \pm 1.5 \text{ mm}$ at ground tests. A microphoto sensor for detecting reflected light from one of fan blades is used to monitor rotation rates. While the winding motor is working (about 1 s), an LED blinks every 60 rotations of the fan. The blinking motions are projected on to close-up images, from whose periods the rotation rates can be estimated.

3.2 Illumination

In order to get higher quality images of ice crystals in cirrus clouds where downward scattered light is weak, the illumination for the close-up camera was changed from natural diffused light to a bundle of LED lamps with a diffusion plate. This method of illumination ensures particle images in sharp con-

Fig. 3. Relationship between rotation rates of a fan and flow rates of air.

trast with the background. This modification also makes nighttime observations possible.

4. Determination of the sampling volume and the collection efficiency

In order to deduce the number density of ice crystals from the number of them collected on the film, it is necessary to estimate the flow rate of air and the collection efficiency for ice crystals.

First, we examined the relation between the rotation rates of the fan and the flow velocity. Figure 3 shows a linear relationship between them. Experiments in a decompression chamber were carried out to estimate the flow rate at altitudes where cirrus clouds occur. The flow velocity v was estimated from the measurements of differential pressure ΔP between the particle inlet and the surroundings using the following relation:

$$\Delta P = \frac{1}{2} \zeta \rho v^2, \quad (1)$$

where ρ is the density of air and ζ is the unique coefficient of pressure loss by the duct. When the cross section of the duct changes gradually and the pressure loss by fluid friction is negligible, ζ can be assumed to be unity. Figure 4 shows the relation between the ambient air pressure and the flow velocity v at three different rotation rates of the fan (10000, 6000, and 2000 rpm). The differential pressure decreases with decreasing atmospheric pressure, which makes the degree of error more serious as shown by error-bars in Fig. 4. The flow velocity did not change significantly with atmospheric pressure at a constant rotation rate of the fan until the pressure was reduced to about 200 hPa, which commonly corresponds to the altitude of cirrus cloud tops. Although, beyond 200 hPa, it was difficult to exactly estimate the flow velocity, it is suggested that the

Fig. 4. Dependence of the flow velocity on ambient pressure at three different rotation rates of the fan. Vertical solid lines indicate the magnitude of errors in measurement of the velocity.

flow velocity should be constant at altitudes where cirrus clouds occur. Since the relation between the rotation rates and the flow velocity is linear, monitoring the rotation rates by using the microphoto sensor enables us to evaluate the flow rate.

Ascent velocities of the new HYVIS are another factor which has an influence on the flow velocity. During the ascent of the HYVIS, ambient air flow accelerates the air that goes through the nozzle. Figure 5 shows the relation between the ambient air speed U_∞ and the flow velocity v at the nozzle base obtained from wind tunnel experiments. In both the case (a) and the case (b), the flow velocity has a tendency to increase linearly with increasing U_∞ , except for smaller values of U_∞ . It is found from the experimental data of case (b) that the linear relation between v and U_∞ holds when ambient air speeds are higher than the flow velocities at the nozzle top and otherwise v is insensitive to U_∞ . Experimental data at smaller values of U_∞ are not available for the case (a). The inconsistency of flow velocities between cases (a) and (b) is supposed to result from slightly different inner shapes of the two units of the new HYVIS used, particularly the clearance between the nozzle base and the film surface. Ascent velocities of the new HYVIS change within the range of air speeds where the linear relation is satisfied. Therefore, the following linear relation, derived by interpolating the two relations for the cases (a) and (b), will be used to estimate the flow velocity at the nozzle base:

$$v = (0.88v_5 - 2.74) + (0.025v_5 + 0.55)U_\infty, \quad (2)$$

where v_5 is the flow velocity at $U_\infty = 5 \text{ m s}^{-1}$.

To determine the collection efficiency of the new HYVIS for ice crystals, a calculation was carried out on the basis of the collection efficiency of particles

Fig. 5. Change in the flow velocities with ambient air speed (U_∞).

Fig. 6. Calculated collection efficiencies of the new HYVIS for cloud particles at 200 hPa at a flow velocity of 12 ms^{-1} . Shapes of particles treated are spherical droplet (solid line), hexagonal plate (long-dashed line, $h/d = 0.2$), and hexagonal cylinder (short-dashed line, $d/L = 0.5$), where h and L refer to the thickness of plates and the length of cylinders, respectively, and d is the diameter of circle circumscribed to basal plane of ice crystals.

Fig. 7. Vertical profiles of temperature (solid line), relative humidity (dashed line) and wind measured by a rawinsonde combined with the new HYVIS launched at 1030 on 8 June 1995.

determined by Ranz and Wong (1952) for round jets. This treatment needs to estimate the correction factor for Stokes drag. For Reynolds number less than 0.01, the correction factor for non-spherical particles has not been determined. However, this factor was estimated by extrapolating the experimental results obtained at larger Reynolds numbers. The assumption is made here that the shapes of hexagonal plates and hexagonal cylinders can be approximately expressed by oblate spheroids and circular cylinders, respectively. Figure 6 shows the calculated collection efficiencies of spherical droplets, hexagonal plates (aspect ratio 0.2), and hexagonal cylinders (aspect ratio 2) as types of collected particles, under the condition where the atmospheric pressure is 200 hPa and the flow velocity at the nozzle base is 12 ms^{-1} . For both the hexagonal plates and the hexagonal cylinders, the collection efficiencies are unity when their maximum sizes are larger than $10 \mu\text{m}$. Since the aspect ratios of nascent ice crystals around $10 \mu\text{m}$ in size are considered not to deviate greatly from unity, it is reasonable to assume that all ice crystals larger than $10 \mu\text{m}$ are collected.

5. Some examples of cirrus cloud observations with new HYVIS

The new version of HYVIS is attached to a balloon with a rawinsonde and a radiation sonde (Asano *et*

Fig. 8. Vertical structures of the cirrostratus measured by the new HYVIS launched at 1030: (a) ice water content; (b) number concentration of ice crystals. Thick-dashed lines are derived from close-up images, and dotted lines are derived from microscopic ones.

Fig. 9. Same as Fig. 8, except for the 1631 case.

al., 1994) and they are launched into clouds. This combination provides us with vertical profiles of microphysical, thermodynamic, and radiative properties in cirrus clouds. Two examples for the microphysical properties in cirrostratus clouds are shown in this section. Cirrostratus associated with a stationary (Baiu) front was observed over the Tsukuba Area, Japan, on 8 June 1995. The balloon with the above combination was launched at 1030 and 1631 JST (hereafter all times are Japan Standard Time). Figure 7 shows profiles of temperature, rel-

ative humidity, and wind obtained from the 1030 sounding. On the observation day, the tropopause located at almost the same altitude as the cloud tops (~ 13.5 km) and a jet core was located about 200 km north of the observation site.

Figures 8 and 9 show the vertical distributions of ice water contents and number concentrations of ice crystals computed from particle images for the 1030 and 1631 cases, respectively. Ice water contents were obtained using the same method as Murakami and Matsuo (1990). The sizes of particles

Fig. 10. Change in size distributions of ice crystals along the ascent of the new HYVIS: (a-1), (a-2) and (a-3) for the 1030 case; (b-1), (b-2), (b-3) and (b-4) for the 1631 case. Dashed lines in each panel are regression curves and their formulae are shown at the top of each panel.

which were analyzed for microscopic and close-up images are under $200\ \mu\text{m}$ and above $50\ \mu\text{m}$, respectively. It was a common feature in Figs. 8 and 9 that, in middle and lower levels, ice water contents held values under $0.01\ \text{gm}^{-3}$ and number concentrations from microscopic and close-up images were several to several tens of crystals per liter and about 10^2 crystals per liter, respectively. High concentrations of ice crystals were confined to the upper layer of about 300 m deep for the 1030 case, and to the upper layer of about 2 km deep for the 1631 case. Simultaneous radar observations suggested that the new HYVIS penetrated generating cells embedded in cirrostratus.

Size distributions from close-up and microscopic images were combined at 250 m intervals and their vertical changes are shown in Fig. 10. Every size dis-

Fig. 11. Examples of microscopic images: (a) at 12.8 km MSL (-59°C) for the 1030 case; (b) at 12.8 km MSL (-57°C) for the 1631 case.

tribution could be approximated by a gamma distribution. Major shapes of ice crystals observed in the clouds were bullets, columns, bullet rosettes, and combinations of columns and plates. A considerable number of plane-type crystals were also found in lower levels in each case. For both cases, high concentrations (more than 100 particles per liter) of ice crystals were found near the cloud tops. The main component of the crystals observed there was the bullet (and bullet rosette) of $100\text{--}250\ \mu\text{m}$ in size for the 1030 case while it was the nascent bullet rosette of about $50\ \mu\text{m}$ for the 1631 case. Examples of microscopic images are shown in Fig. 11.

6. Conclusions

A new version of Hydrometeor Videosonde for measuring cirrus clouds has been described. By adding a suction fan, sufficient sampling volume could be obtained to determine the form of size distributions at 250 m intervals in cirrus clouds with low ice crystal concentrations. Adding a suction fan greatly enhances the collection efficiencies for smaller particles and enables reliable ice crystal spectra for sizes down to $10\ \mu\text{m}$ to be obtained.

The new HYVIS measurements also provide information on detailed shapes of ice crystals. They should lead to advanced studies on microphysical

structures and radiative properties in cirrus clouds and increase our understanding of mechanisms for the formation and maintenance of cirrus clouds.

Acknowledgments

This work was done as a part of the JACCS/MRI program which is supported by the Science and Technology Agency of Japanese Government. The authors wish to thank the staff of the Aerological Observatory, and Mr. H. Mizuno and Mr. Y. Yamada, M.R.I. for their cooperation in the balloon observations. Thanks are also extended to Mr. K. Akaeda of JMA for providing the radar data. The authors would like to express their thanks to the staff of Meisei Electric Co. for their great help during the development of the HYVIS. The authors are also grateful to the technical staff at the Wind Tunnel Facility of M.R.I. for their cooperation in sampling volume experiments, and to two anonymous reviewers for their constructive comments.

References

- Asano, S., JACCS/MRI Research Group, 1994: Japanese Cloud Climate Study (JACCS): Research plan and preliminary results. *Preprint of the 8th Conf. Atmos. Radiation, Nashville, TN, U.S.A., Amer. Meteor. Soc.*, 282–284.
- Barton, I.J., 1983: Upper level cloud climatology from orbiting satellite. *J. Atmos. Sci.*, **40**, 435–447.
- Liou, K.N., 1986: Influence of cirrus clouds on weather and climate processes: A global perspective. *Mon. Wea. Rev.*, **114**, 1167–1199.
- Magono, C. and S. Tazawa, 1966: Design of “snow crystal sonde”. *J. Atmos. Sci.*, **23**, 618–625.
- Mizuno, H., T. Matsuo, M. Murakami and Y. Yamada, 1994: Microstructure of cirrus clouds observed by HYVIS. *Atmos. Res.*, **32**, 115–124.
- Murakami, M. and T. Matsuo, 1990: Development of the hydrometeor videosonde. *J. Atmos. Ocean. Tech.*, **7**, 613–620.
- Murakami, M., T. Matsuo, T. Nakayama and T. Tanaka, 1987: Development of cloud particle video sonde. *J. Meteor. Soc. Japan*, **65**, 803–809.
- Ranz, W.E. and J.B. Wong, 1952: Impaction of dust and smoke particles on surface and body collectors. *Ind. Eng. Chem.*, **44**, 1371–1381.

強制吸引式雲粒子ゾンデの開発

折笠成宏・村上正隆

(気象研究所)

低濃度の氷晶からなる巻雲を測定するために新型の雲粒子ゾンデを開発した。このゾンデは倍率の異なる2台の小型ビデオカメラを搭載しており、粒径 $7\mu\text{m}$ ～ 5mm の粒子の映像を1.6 GHzのマイクロ波を通して地上に伝送する。従来の雲粒子ゾンデでは、サンプリング体積が小さいために、雲粒子の数濃度が低い雲の粒径分布が正確に評価できなかった。この点を克服するために、吸引用の小型ファンを付加することによって十分なサンプリング体積を確保した。また、周囲の気圧変化やゾンデの上昇速度によるサンプリング体積の変化を室内実験によって評価した。捕捉率の理論的計算から、 $10\mu\text{m}$ 以上の粒子が全て捕捉されると考えられる。

強制吸引式雲粒子ゾンデによる巻雲の観測例から、 $10\mu\text{m}$ 以上の氷晶の粒径分布を250 m間隔で精度良く決定できることがわかった。この雲粒子ゾンデの観測結果は、巻雲の生成や維持の機構を理解するのに有益な情報を与える。