Microphysical Properties of Mid-latitude Cirrus Clouds Observed with Hydrometeor Videosonde

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Introduction

High-level ice clouds play a complex role in the global energy budget by affecting infrared radiation emitted by the earth's surface. In order to understand the climate system, it is necessary to increase our knowledge about the microphysical, radiative, and optical properties of cirrus clouds. In situ measurements on microphysical structures of cirrus clouds have been made by using special, high-altitude flying aircraft. 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 at sizes smaller than about 100 µm and cannot detect details of crystal habits.

To overcome these difficulties, a special sonde called the Hydrometeor Videosonde (HYVIS) was developed (Murakami and Matsuo 1990). Having applied this HYVIS to cirrus cloud observations (Mizuno et al. 1994), we learned that it was necessary to obtain sufficient sampling volume in cirrus clouds with low ice crystal concentrations. Moreover, the weakness of the downward scattered light degraded the quality of particle images, which made it necessary to change the illumination from natural to artificial light. To meet these requirements, we have built a new version of HYVIS that is an improvement over the original.

Outline of the New Hydrometeor Videosonde

A cutaway view of the new HYVIS is shown in Figure 1. It has two video cameras with different magnifications to take pictures of hydrometeors from 7 µm to 5 mm in size. Hydrometeors are sucked through a particle inlet (1 cm in diameter) and collected on a section of transparent 35 mm leader film over which silicon oil is applied. For the first 6 s, the microscopic camera takes pictures of small ice crystals of the order of 10 to 100 µm in size. At the beginning of 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.

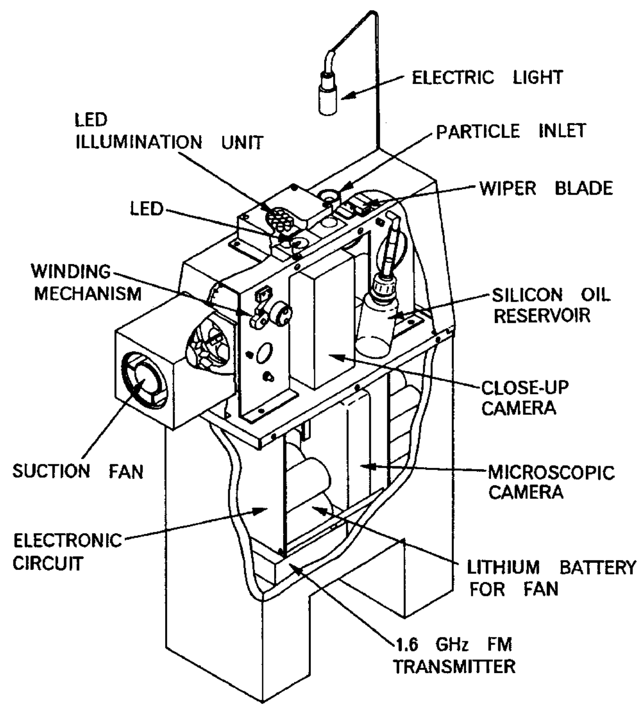

Figure 1. Cutaway view of the new version of HYVIS.

As shown in Figure 1, the new HYVIS with a small suction fan (V484M, Micronel) forces hydrometeors to fall through the particle inlet (cylindrical nozzle). The velocity of air flow at normal temperature and 1 atm. is approximately 12 ms^{-1} at the base of the impactor nozzle, which corresponds to a flow rate of about 1 ls^{-1}, five times more than the rate of the original HYVIS (natural ventilation type).

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 over a 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.

Determination of the Sampling Volume and the Collection Efficiency

In order to deduce the number density of ice crystals from the number of crystals collected on the film, it is necessary to estimate the flow rate of air and the collection efficiency for ice particles. Experiments in a decompression chamber were carried out to estimate the flow rate at altitudes where cirrus clouds occur. The flow rate did not change significantly with atmospheric pressure at a constant rotation rate of the fan until the pressure is reduced to about 200 hPa, which often corresponds to an altitude of cirrus cloud tops. Although, beyond 200 hPa, it was difficult to estimate the flow rate exactly, our results suggest that the flow rate should be constant at altitudes where cirrus clouds occur. Since our results show that the relation between the rotation rates of the fan and the flow velocity is linear, monitoring the rotation rates by using a microphoto sensor enables us to evaluate a flow rate.

Ambient air speed is another factor which has an influence on the flow velocity. During the ascent of the HYVIS, the ambient air flow accelerates the air which goes through the nozzle. On the basis of wind tunnel experiments, we will assume the following relation between the flow velocity v at the nozzle base and the ambient air speed U∞:

$$\upsilon = (0.88\upsilon_5 - 2.74) + (0.025\upsilon_5 + 0.55)U_\infty \quad (1)$$

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

To determine the collection efficiency of the new HYVIS for ice crystals, a theoretical calculation was carried out on the basis of the collection efficiency of particles for round jet determined by Ranz and Wong (1952). As shown in Figure 2, the calculation indicates that for both a hexagonal plate (aspect ratio 0.2), and a hexagonal cylinder (aspect ratio 2), the collection efficiencies reach unity before their maximum size increases to 10 µm. Since the aspect ratios of nascent ice crystals around 10 µm in size are considered not to deviate greatly from unity, it is reasonable to assume that all ice crystals larger than 10 µm are collected.

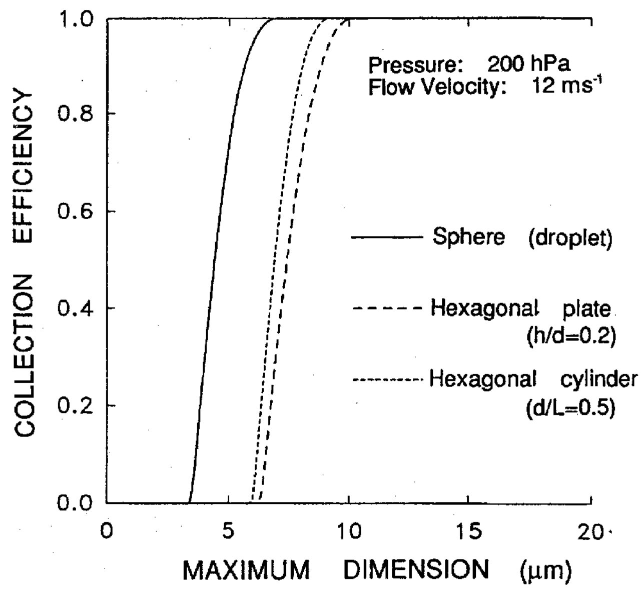

Figure 2. Calculated collection efficiencies of the new HYVIS for three types of particles.

Example of Cirrus Cloud Observations with the New HYVIS

The new version of HYVIS is attached to a balloon with a rawinsonde and a radiation sonde (Asano et al. 1994) and is launched in clouds. This combination provides us with vertical profiles of microphysical, thermodynamic, and radiative properties in cirrus clouds.

This section will concentrate on the microphysical properties obtained from cirrostratus observation with the new HYVIS. 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 JST. On the observation day, the tropopause existed at almost the same altitude as the cloud tops (~13.5 km), and a jet core was located about 200 km north of the site.

Figure 3 shows the vertical distributions of ice water content (IWC) and the number concentrations of ice crystals computed from particle images. They were obtained using the same method as Murakami and Matsuo (1990). The particles analyzed for microscopic and close-up images are under 200 µm and above 50 µm, respectively. In middle

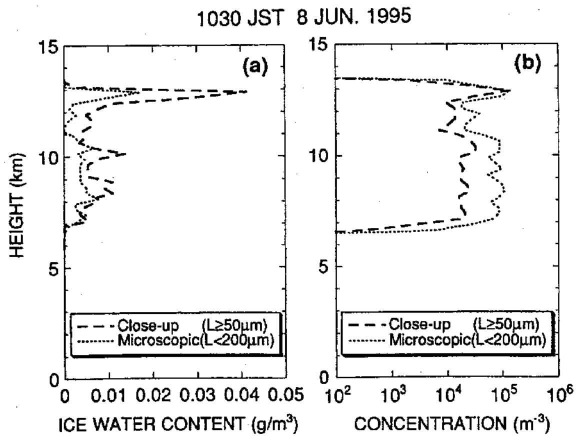

Figure 3. Vertical structures of the cirrostratus measured by the new HYVIS launched at 1030 JST: (a) ice water content; (b) number concentration of ice crystals.

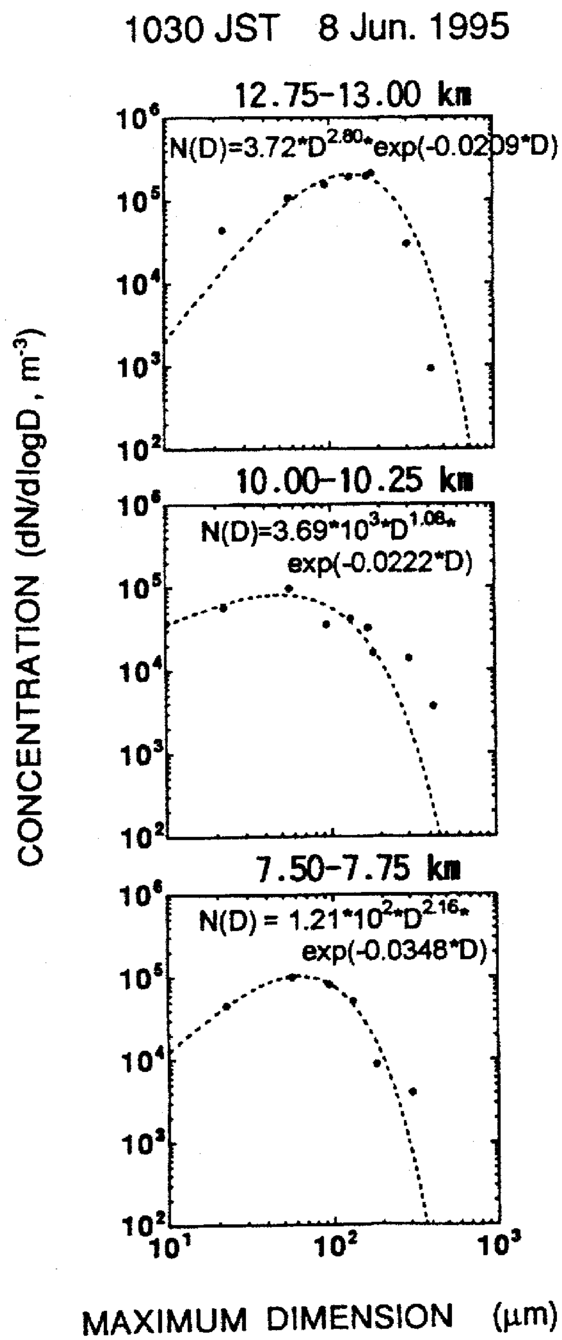

Figure 4. Change in size distributions of ice crystals along the ascent of the new HYVIS launched at 1030 JST. Dashed lines in each panel are regression curves and their formulae are shown at the top of each panel.

and lower levels, IWC held values under 0.01 gm^{-3} and number concentrations from microscopic and close-up images were several to several tens per liter and about 10^2 per liter, respectively. High concentrations of ice crystals were confined to the upper layer of about 300 m, where the IWC values reached 0.04 gm^{-3} and number concentrations were about 200 particles per liter. 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. Their vertical changes are shown in Figure 4. Every size distribution could be approximated by gamma distribution.

The second balloon was launched six hours later (at 1631 JST). For both cases, high concentrations of ice crystals were found near the cloud tops. The main component of the crystals observed there was bullet (and bullet rosette) of 100-250 µm in size in the 1030 case, while a nascent bullet rosette of about 50 µm was observed in the 1631 case. Examples of microscopic images are shown in Figure 5. Major shapes of ice crystals observed in the clouds were bullets, columns, bullet rosettes, and combinations of columns and plates.

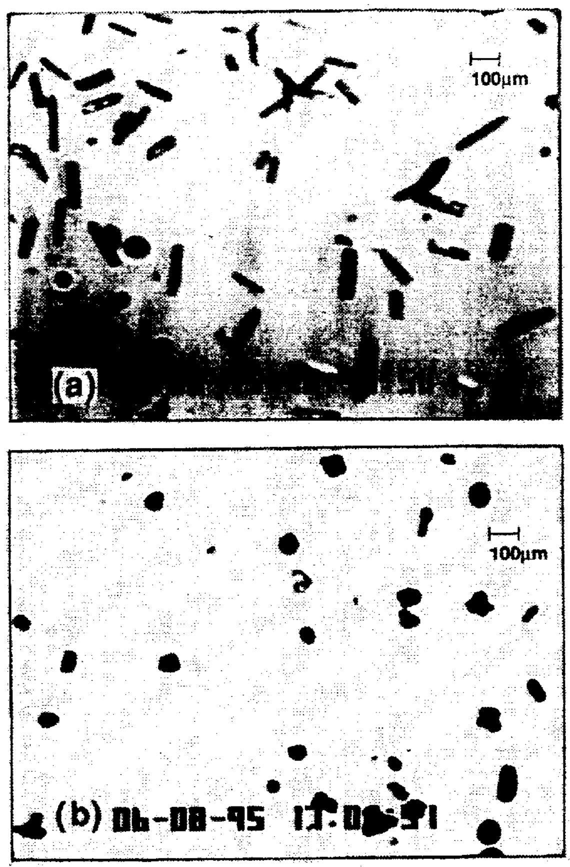

Figure 5. Examples of microscopic images: (a) at 12.8 km MSL (-59° C) for the 1030 case; (b) at 12.8 km MSL (-57° C) for the 1631 case.

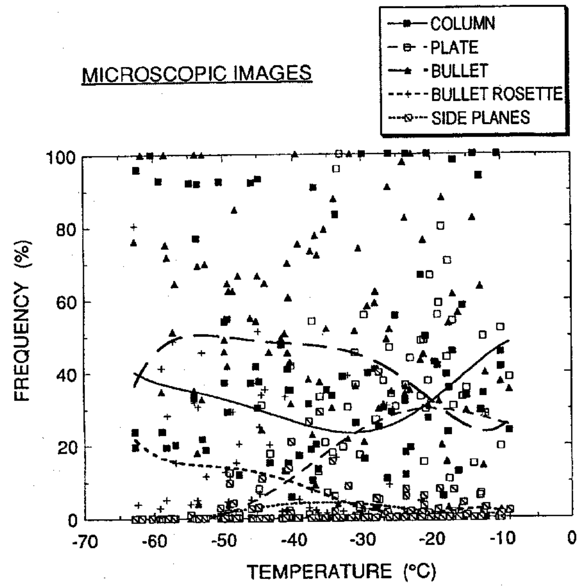

Figure 6. The presence frequency of ice crystals for five crystal habits plotted against temperature. Each line indicates an averaged frequency for every data except 0%.

Microphysical Properties in Cirrus Clouds

We have launched 14 units of the new version of HYVIS for the last few years. To summarize the microphysical properties of cirrus clouds observed at Tsukuba, Japan, to date, we examined the dependence of the ice crystal habit, IWC, and number concentrations of ice crystals on air temperature.

The frequencies of ice crystals for given crystal habits were calculated from 500 m height-average crystal counts. In Figure 6, these values were plotted as a function of the average temperature of each layer for microscopic images. Columns and bullets were commonly observed throughout the temperature range indicated. At temperatures lower than about -30° C, bullet rosettes were also common. The frequency of plates (developed in one plane) had a significant tendency to increase with increasing air temperature when the temperature was warmer than -40° C.

The dependence of IWC on the air temperature appears in Figure 7. There was no correlation between the temperature and the IWC or the ice crystal concentration (not shown here) in contrast to the observational result from Heymsfield (1977), who found that the IWC and ice crystal concentration were dependent on the vertical velocity and temperature. In his case, aircraft sampling was performed in very uniform and deep ice clouds and typically in the growth region for ice crystals. On the other hand, clouds in our case were rather uniform, but often had multi-layer structures. Our data included sublimation (evaporation) regions of ice crystals, so that the IWC and ice crystal concentration were widely scattered at any given temperature, ranging from $4 x 10^{-6}$ to $5 x 10^{-1}$ gm^{-3} and from $6 x 10^{-1}$ to $3 x 10^{2}$ per liter, respectively. The data shown in Figure 7 suggested that the IWC or the ice crystal concentration did not always show a strong temperature dependence, although vertical velocities were not taken into consideration here. Further, the figure indicated that the IWC had a significant tendency to have higher values in layers with supersaturation over ice.

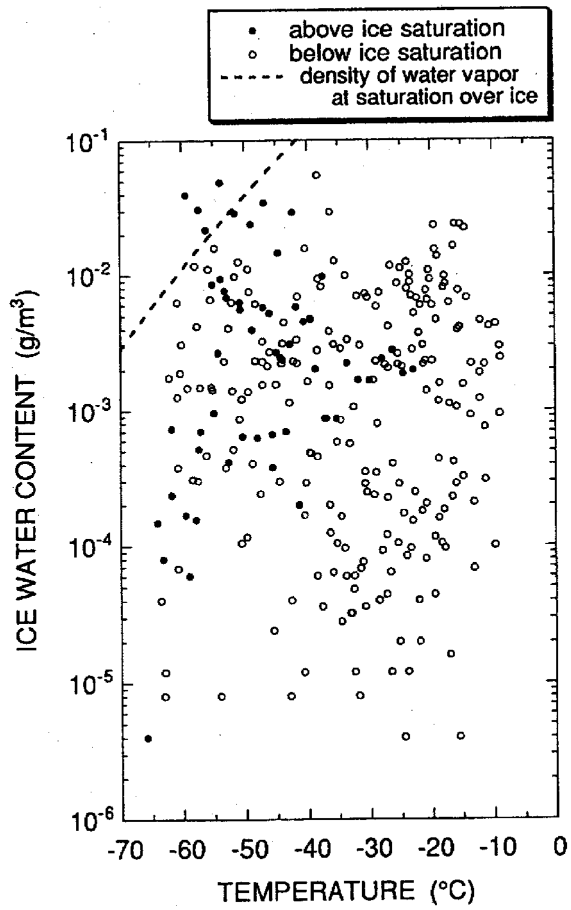

Figure 7. Ice water content plotted against temperature. Ice water content was calculated at 250-m intervals.

Conclusions

A new version of the Hydrometeor Videosonde for measuring cirrus clouds was described. By adding a suction fan, we were able to obtain sufficient sampling volumes to determine the form of size distributions at 250-m intervals in cirrus clouds with low ice crystal concentrations. The new HYVIS also enabled us to obtain reliable size distributions of ice crystals larger than 10 µm.

The new HYVIS observations suggested that there was no correlation between air temperature and IWC or ice crystal concentration. The IWC and ice crystal concentration were found to have a great deal of scatter at any given temperature, although vertical velocities were not discussed here.

The new HYVIS measurements also provide us with the 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

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