P1.53

CHARACTERISTICS OF CIRRUS CRYSTAL SHAPES FROM HYDROMETEOR VIDEOSONDE DATA

Narihiro Orikasa* and Masataka Murakami

Meteorological Research Institute, Tsukuba, Ibaraki 305-0052, Japan

1. INTRODUCTION

Cirrus clouds have an important influence on the Earth's radiation budget and climate. The net effect of cirrus on the surface depends on both macrophysical properties (cloud height, geometrical thickness, and temperature) and microphysical properties (ice crystal size, shape, density). Particularly ice crystal habit is one of the least known but most complicated factors to quantify the impact of cirrus clouds, because the crystal shape determines the terminal velocity, projected cross-sectional area, and ice water content and ice particle population of different shapes affect the lifetime, scattering properties and precipitation growth rate of ice clouds.

The microphysical properties of cirrus clouds are closely interlinked with their optical properties. The terminal velocity, the extinction coefficient, and the effective radius of ice particle are related to the projected cross-sectional area. Most studies have used habit-dependent relations between ice particle diameter (maximum dimension) and cross-sectional area for estimating the total area of particle populations (e.g., Mitchell 1996, hereafter M96). However, the appropriateness of such empirical equations is uncertain, and the estimating error should be examined case by case. Heymsfield et al.(2002) proposed a general approach for improving the method of deriving the microphysical properties (bulk density and mass of ice particles) of ice clouds from two parameters: the maximum dimension and the projected cross-sectional area of ice particle. Recently, the cross-sectional area data from past studies were evaluated and parameterized for each crystal shape by introducing the shape-sensitive parameter, area ratio (Heymsfield et al. 2003, hereafter HM03).

Most of microphysical in situ data from the previous studies were obtained from aircraft observations. In contrast, balloon-borne hydrometeor videosonde (HYVIS) (Murakami and Matsuo 1990; Orikasa and Murakami 1997) has great advantage for cirrus cloud observation; the videosonde can easily reach the highest clouds, up to cirrus top, and has sufficient resolution to distinguish the shapes of ice particles smaller than 100 μm, and can obtain vertical distributions of hydrometeors at fine resolution.

* *Corresponding author address:* Narihiro Orikasa, Meteorological Research Institute, Tsukuba, Ibaraki, 305-0052, Japan; e-mail: norikasa@mri-jma.go.jp.

In this paper, we analyzed microphysical measurements from the HYVIS observation, focused on the crystal shapes. The occurrence frequency and the area ratio distribution are investigated for each ice crystal habit.

2. INSTRUMENTATION AND DATA

We limited our data analysis to in situ measurements of cirrus clouds observed by 35 launches of the HYVIS, which was conducted from Tsukuba (36.0N, 140.1E), Japan, in spring to early summer between 1994 and 2004. Those clouds were high-level ice clouds generally associated with mid-latitude fronts of synoptic scale lows.

The HYVIS has two video cameras with different magnifications (close-up and microscopic cameras) to take pictures of particles larger than about 7 μm. Ice particles are collected on a transparent film with a thin coating of silicone oil. After the launch of the HYVIS (typical ascent rate of about 5 m s^{-1}), the particle images are transmitted via a 1687MHz microwave to a ground station in real time and videotaped.

Ice crystal habits from the HYVIS image data were identified in several types by the human eye. In this study the microscopic images in several cases were analyzed by image processing software to obtain the cross-sectional area (A), maximum dimension (D), major axis (a), and minor axis (b) of each ice particle. The shape-sensitive parameters, such as area ratio ($=A/(\pi D^2/4)$) and aspect ratio ($=b/a$), are analyzed to examine the dependency on various parameters such as dimension, crystal habits, or vertical positions.

3. MICROPHYSICAL CHARACTERISTICS

3.1 *Crystal Habit Frequency*

The current work classifies the cirrus particle images measured by the HYVIS into several habit categories: column, bullet, plate, side plane, bullet rosette, assemblage of plates, and aggregation (combination) of column and plate. Figure 1 shows the percent frequency of ice crystal habits as a function of ambient temperature; the frequency was normalized in each temperature range of 5 degrees C. The most dominant crystal type was bullet at temperature ranges from -60° to -20°C. The plate type was dominant at temperatures warmer than -20°C, whereas the column or the bullet rosette became dominant at temperatures colder than -60°C. Colder than -40°C, the frequency of bullet rosette and column crystals had significant tendency to increase with decreasing temperature; while warmer than -40°C,

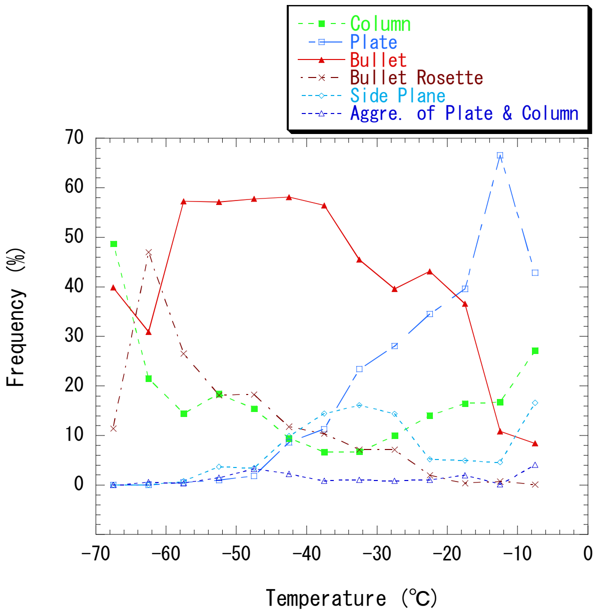

Fig. 1. Percent frequency of ice crystal habits as a function of temperature. The frequency is normalized in each temperature range of 5°C.

the plate type had a noticeable trend to increase with increasing temperature. The habit distribution in this study is consistent with recent laboratory studies measured with the static diffusion chamber (Bailey and Hallett 2004), in the context of the habit transition region around -40°C.

Figure 2 shows the total counts in each crystal type as a function of temperature and size displayed as a ribbon graph. Platelike crystals (side plane or plate) with larger sizes can be more dominant at temperatures between -10° and -20°C than at any other temperature ranges. Contrary to column crystal, bullet and bullet rosette types show a distinct feature that particles of any size more commonly appeared in temperatures abound -40°C.

3.2 *Axis ratio*

The aspect ratio of each ice particle was interpreted as the axis ratio (minor length/major length) in this study. The axis ratios of column, bullet, and bullet rosette crystal measured with the HYVIS are shown in Fig. 3 as a function of dimension and temperature. Although only seven cases (observed in 2004) were analyzed, the column and bullet crystals had size dependency which showed the decreasing tendency with increasing dimension, whereas the bullet rosette had no significant tendency, which suggests that the growth of bullet rosette should be more isotropic. We found no clear temperature dependency of the axis ratio in three crystal shapes.

3.3 *Area ratio*

The area ratio of various types of ice crystal habit was investigated in different field projects and found to be useful parameter for particle shapes in recent studies (e.g., HM03). Similar to Fig. 3, the area ratios of four crystal habits were plotted as shown in Fig. 4, compared to previous studies of M96 and HM03. The general trend in this study is found to be close to HM 03 study. The M96 curves in Figs. 4a and 4b exhibit higher area ratio over the size ranges, possibly due to the difference of sampling conditions (generally sampled at warmer temperatures). The slope of the area ratio data in case of side planes was shallower than that of other three types as shown in Fig. 4c, which is similar trend to other studies. On the other hand, Fig. 4d in case of bullet rosette crystals shows the stronger decreasing trend with increasing dimension in this study. It requires further investigation to identify the causes.

When we applied the cross-sectional area to dimension power laws reported by M96 to the HYVIS data, Fig. 5 shows the ratio in each cirrus layer (250 m height interval) of calculated area (*Ac*) by the equations to measured area (*A*) by the image analysis. We found that the *Ac* overestimates 20 to 80% in cloud vertical column, which is highly variable among individual cases (seven cases at this stage). Although this overestimation was contributed by different crystal habits, the main cause of this error is attributed to the current power laws (by M96) of columnar and bullet rosette type as shown in Fig. 4.

A power law fit to the area ratio of all data in seven cases is shown in Fig. 6. The fitting curve decreases from about 0.6 for 50-μm particles to about 0.3 for 300-μm particles, which is smaller values than the replicator data of cirrus particles by HM03 but shows a generally similar trend to their result.

The area ratio also has a significant trend in vertical distributions as depicted in HM03 study. Figure 7 shows the plot of area ratios measured with the HYVIS for each cloud layer divided into five equal-thickness between cloud top and cloud base for individual cases. The slope of the area ratio trend was steep in the upper cloud layers, whereas the slope appears to show a gentle trend in the lower half of clouds, although the area ratio were highly variable.

4. SUMMARY

Habit frequency of cirrus clouds measured with the HYVIS was presented in this study. Those clouds were generally associated with synoptic-scale depressions. Bullet crystal was predominant at temperature between -20° and -60°C. Colder than -40°C the averaged frequency of bullet rosette and column increased with decreasing temperature, whereas warmer than -40°C the frequency of plate increased with increasing temperature. Large platelike crystals occurred more frequently at temperatures between -10° and -20°C than at any other temperature ranges. Single bullet and bullet rosette crystals showed a remarkable high frequency around -40°C. These results are consistent with previous and recent laboratory studies.

The shape-sensitive parameter, such as a area ratio, can be an important information to deduce more accurate microphysical and optical properties of ice clouds. The size and temperature dependency of area ratio (or axis ratio) was examined from the HYVIS measurements. A large error of total cross-sectional area of ice particle population (same as the extinction coefficient of clouds) might be introduced by using the conventional power-law relationships between area and dimension. Not only the crystal shapes but also vertical positions can influence the area ratio distributions. Parameterizations for microphysical properties on the basis of crystal shapes require such information on several factors, to assess differences between individual cases.

Acknowledgements

The HYVIS observation was assisted by the JMA TATENO Aerological Observatory, Tsukuba. This study was supported by the Science and Technology Agency of Japanese Government.

References

Bailey, M. and J. Hallett, 2004: Growth rates and habits of ice crystals between -20° and -70°C. J. Atmos. Sci., **61**, 514-544.

Heymsfield, A. J. and coauthors, 2002: A general approach for deriving the properties of cirrus and stratiform ice cloud particles. J. Atmos. Sci., **59**, 3-29.

Heymsfield, A. J., and L. M. Miloshevich, 2003: Parameterizations for the cross-sectional area and extinction of cirrus and stratiform ice cloud particles. J. Atmos. Sci., **60**, 936-956.

Mitchell, D. L., 1996: Use of mass- and area-dimensional power laws for determining precipitation particle terminal velocities. J. Atmos. Sci., **53**, 1710-1723.

Murakami, M. and T. Matsuo, 1990: Development of the hydrometeor videosonde. J. Atmos. Ocean. Tech., **7**, 613-620.

Orikasa, N., and M. Murakami, 1997: A new version of hydrometeor videosonde for cirrus cloud observations. J. Meteor. Soc. Japan, **75**, 1033-1039.

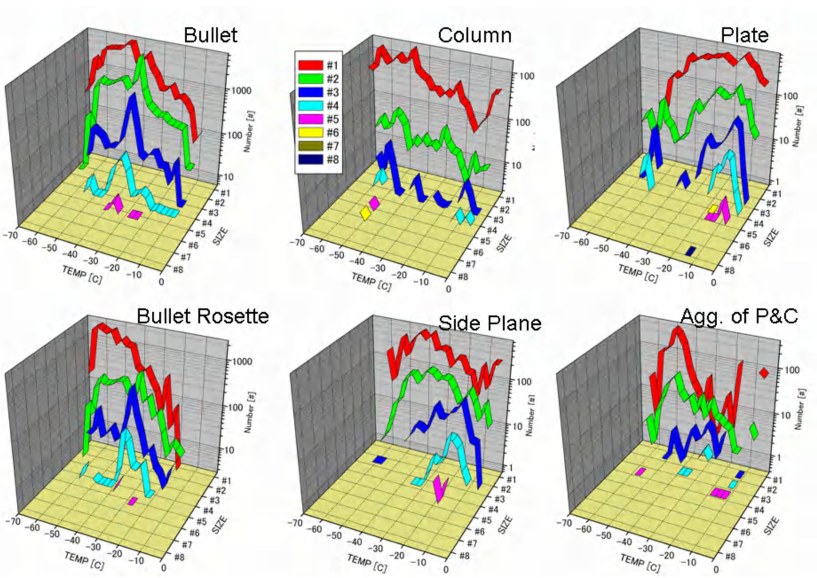

Fig. 2. Total counts in each crystal type as a function of temperature and size. The number of size corresponds to bin number for close-up camera, whose bin size is about 115 μm.

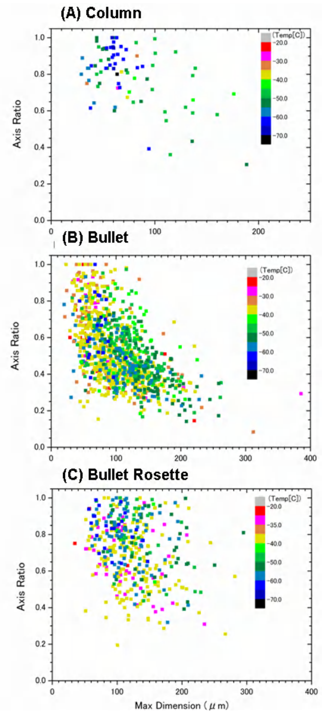

Fig. 3. Axis ratio vs maximum dimension relationships for a crystal habit of (a) column, (b) bullet, or (c) bullet rosette. Data points are colored according to the ambient temperature. Only data for microscopic images were analyzed.

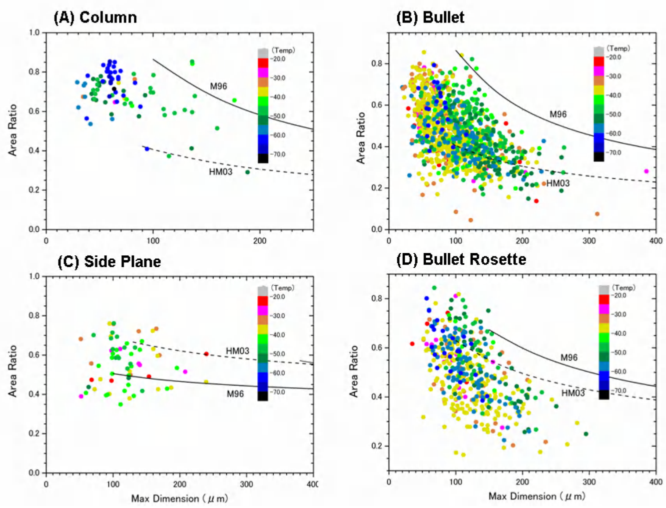

Fig. 4. Area ratio vs maximum dimension relationships for a crystal habit of (a) column, (b) bullet, (c) side plane, or (d) bullet rosette. Data points are colored according to the ambient temperature. For comparison, the M96 curve (solid) indicates the study summarized by Mitchell (1996), whereas the HM03 curve (dashed) indicates the result by Heymsfield and Miloshevich (2003).

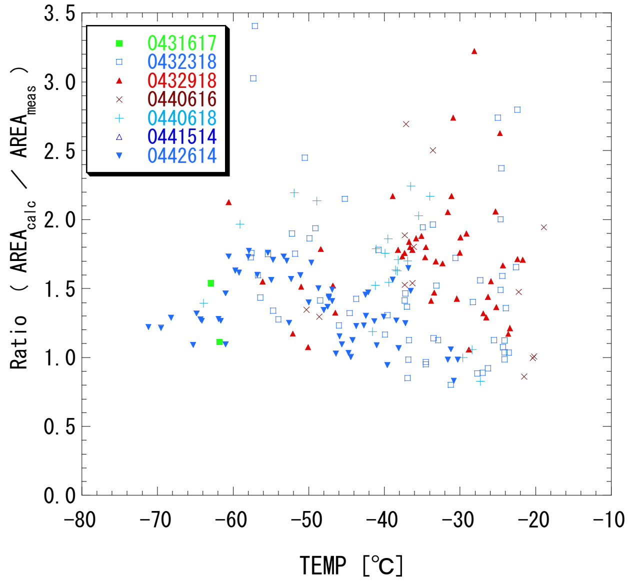

Fig. 5. Ratio between calculated areas from empirical power-laws reported by Mitchell (1996) and measured areas by image analysis as a function of temperature. Seven cases in 2004 (dates in legend) were plotted in each cloud layer (thickness: 250 m).

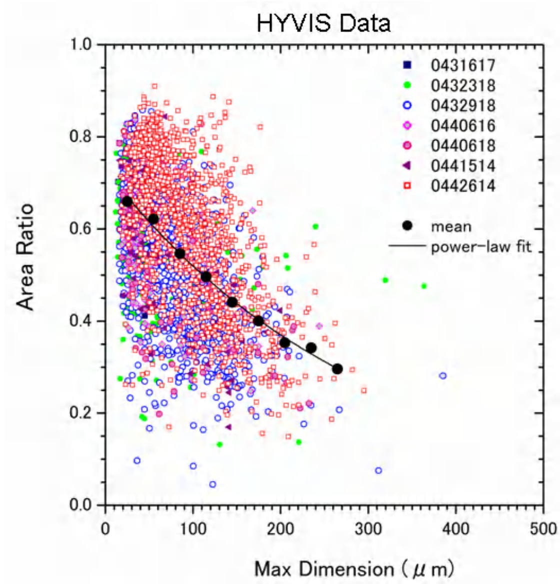

Fig. 6. A power-law fit (solid line) to the mean (dark dots) of the data in 30-μm dimension bins, measured with the HYVIS in 2004 (dates in legend).

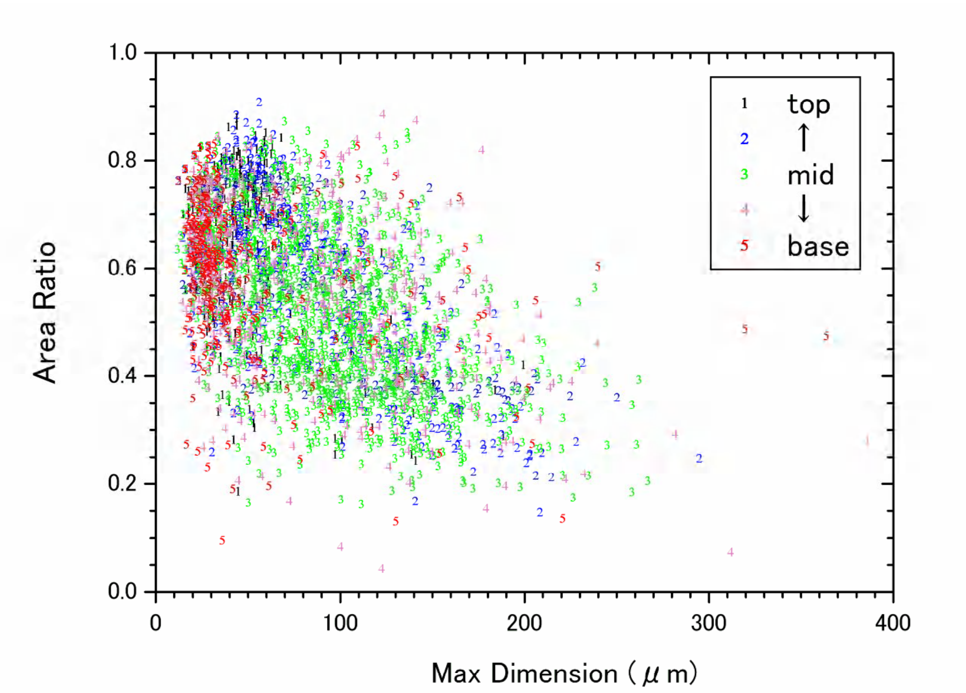

Fig. 7. Normalized height dependency of area ratio vs maximum dimension relationships measured with the HYVIS, shown for a each cloud layer (plotted as the number from the top) divided into five equal-thickness between cloud top and cloud base for individual cases.