# 2A.2 PROPERTIES OF SNOWFLAKES OF DIFFERENT RIMING DEGEREE AND CRYSTAL TYPES


Eszter Barthazy* and Raphael Schefold

Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland


## 1 INTRODUCTION

The properties of snowflakes such as their size distribution, fall velocity, axial ratio or their orientation when falling are important in modelling precipitation processes or in interpreting returned radar power, especially of polarized radar. However, literature on shape and fall velocity measurements of snowflakes of different crystal type and riming degree is scarce and rely generally on a very small set of snowflakes. This is a direct consequence of the instrumental difficulties in measuring properties of single snowflakes.

The Institute of Atmospheric and Climate Science at the ETH has developed an optical instrument (HVSD, **H**ydrometeor **V**elocity and **S**hape **D**etector) which is capable to measure reliably, with high accuracy and automatically the properties of each single snowflake falling through a 77 square cm area (Barthazy, 2003). In addition to the geometrical properties, the fall velocity of the snowflakes can be measured.

A large data set of two winter seasons with about 240 hours of snowfall is available. Ice crystal type and riming degree are determined with Formvar slides (Schaefer, 1956). Preliminary results on fall velocity and axis ratio of snowflakes consisting of different ice crystal types and of different riming degree are presented.

## 2 THE INSTRUMENT

A light source is producing a beam of uniform light directed towards an electronic line scan camera. Precipitation particles falling through the light beam in a gap of the housing of the instrument cast a shadow which is measured by the line scan camera with a scan frequency of 9470 Hz. A top and a side view of the instrument is shown in Fig. 1. The camera is sensitive in two horizontal planes, having a vertical distance of 9.45 mm. Therefore, every hydrometeor is recorded twice, with a slight time difference. To calculate the vertical fallspeed and other parameters of hydrometeors, two corresponding images of hydrometeors have to be matched. A program calculates matches on the basis of different characteristics of the images.


* Corresponding author's address: Institute for Atmospheric and Climate Science, ETH Honggerberg HPP, CH–8093 Zurich, e–mail: eszter@atmos.umnw.ethz.ch


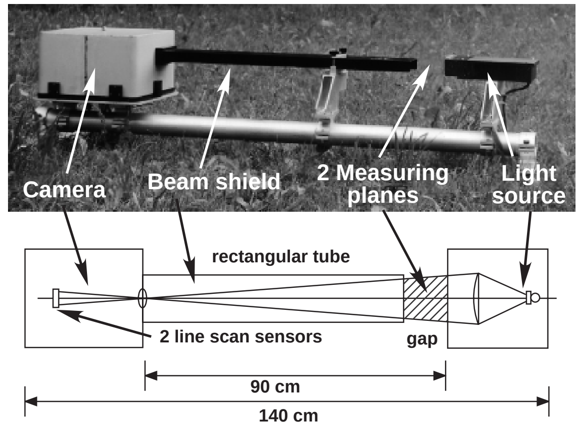


Fig. 1: *Top and side view of the HVSD.*

## 3 DATA

The HVSD was operated in two winter seasons (2001/02 and 2002/03) during 15 cases with a total of 240 hours of snowfall data and a total of 415 Formvar slides. The Formvar slides have been evaluated with a microscope and for each slide the percentage composition of the crystal types is known as well as the distribution of the riming degree and an average riming degree. The riming degree (rim) of the ice crystals was determined according to Mosimann (1995, see also Table 1).

| Riming Degree | Description |
|---|---|
| 0 | unrimed |
| 1 | lightly rimed |
| 2 | moderately rimed |
| 3 | densely rimed |
| 4 | heavily rimed |
| 5 | graupel |

Table 1: *Classification of riming with increasing number of frozen up cloud droplets (Mosimann, 1995).*

In order to study the properties of snowflakes of a given crystal type, the data set of the Formvar slides was reduced to those with one dominant crystal type ($\geq$ 50%). 48 out of the 415 Formvar slides could be attributed to either one of the following crystal types: needles, dendrites, plates or graupel. 343 slides were mainly covered with irregular ice crystals and for 24 slides, no predominant crystal type could be attributed (Table 2).

The sampling times of the Formvar slides have been used to identify time intervals from the HVSD data for a given crystal type. For the sampling time $t$ of a Formvar slide, a time interval of $t \pm 30$ s is chosen to select HVSD data. Depending on the precipitation rate and

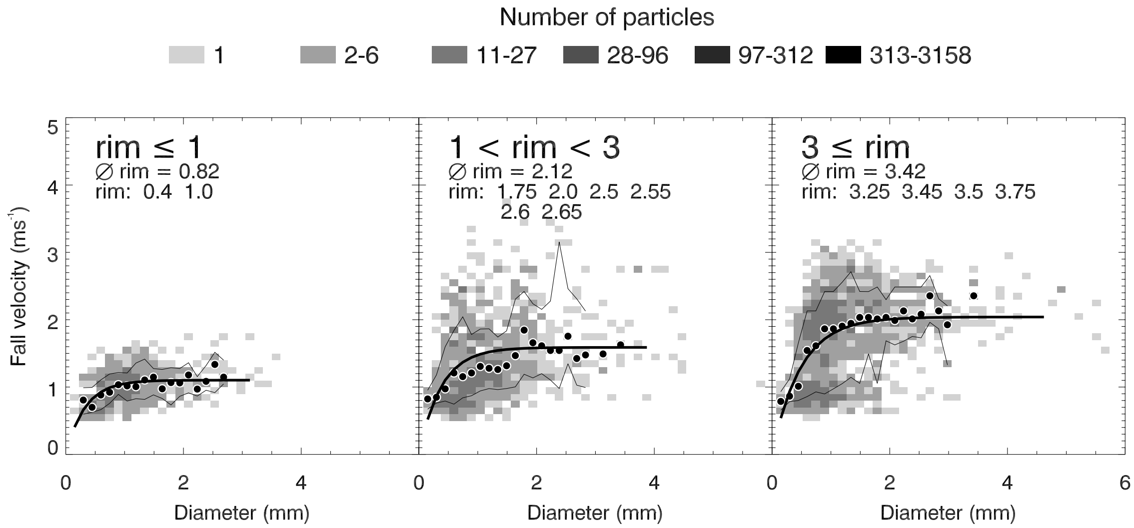


Fig. 2: *Fall velocity versus diameter for snowflakes consisting mainly of needles. The three panels show unrimed, moderately and densly rimed ice particles from left to right. The average riming degree for each subset is printed in each frame as well as the riming degrees of the single Formvar slides contributing to each subset. The thick line shows an exponential fit to the data, the thin curves are the 17- and 83-percentiles, enclosing 66% of the data. The dots mark the median fall velocity for each size category.*

the number of Formvar samples for each given crystal type, between 800 and 37'000 snowflakes are used for the further investigation.

| Crystal type | # formvar slides | # snowflakes (HVSD data) |
|---|---|---|
| Needles | 16 | 2'342 |
| Plates | 8 | 1'495 |
| Dendrites | 20 | 1'232 |
| Graupel | 4 | 768 |
| Irreg. crystals | 343 | 36'748 |

Table 2: *Number of Formvar slides and number of single snowflakes from the HVSD for the ice crystal types investigated.*

## 4 FALL VELOCITY

The fall velocity behaviour of snowflakes depends on the crystal type they consist of as well as on the riming degree. To study a potential relationship of the fall velocity to the riming degree, snowflake data have been split up into three riming regimes. Snowflakes with rim≤1, 1<rim<3, 3≤rim are termed hereafter unrimed, moderately and densly rimed, respectively.

### 4.1 Needles, plates and dendrites

To illustrate the dependence on the riming degree, fall velocity distributions of snowflakes consisting mainly of needles are shown in Fig. 2. The figure has three panels, each showing the measured fall velocity for a different riming regime. The gray shaded pixels shown in all three panels of Fig. 2 measure 0.150 mm on the x-axis, which represents the horizontal resolution of the instrument. On the y-axis, the velocity resolution is set to 0.1 ms$^{-1}$. For each size category, the median fall velocity is marked with a dot, provided that at least five particles were recorded within the size category.

Size-fall velocity relations of snowflakes are usually described by a power law. We have noticed that in most cases an exponential fit is better suited to approximate the fall velocities of snowflakes, especially when snowflakes are observed of a wide range in size. At small sizes, the fall velocity increases rapidly but after reaching a certain value, fall velocity of snowflakes tend to remain almost constant with increasing snowflake size. Therefore, the snowflake data have been fitted with a function of the form

$$v(D) = a_0(1 - e^{-a_1 D}), \quad (1)$$

where $D$ is the diameter in mm and $a_0$ and $a_1$ are fit parameters. Then, the velocity $v(D)$ is obtained in ms$^{-1}$. The fitted size-fall velocity relationships are drawn in Fig. 2 with a heavy line and Table 3 summarizes the fit parameters of all crystal types and riming regimes investigated.

More important than an average (fitted) size-fall velocity relationship for snowflakes is the large scatter of fall velocities for a given size. The thin curves in Fig. 2 enclose 66% of the data (17- and 83-percentiles). In case of a normal distribution this would correspond to an interval of $\pm$ one standard deviation. The percentiles are about 0.5 to 1.5 ms$^{-1}$ apart, giving a reasonable variation of snowflake fall velocity for a given size of $\pm$ 0.3 to 0.7 ms$^{-1}$. This variablility of the fall velocity can most likely be attributed to the natural variation of snowflake properties such as the geometrical form of the snowflake, its density, a certain variability of the riming degree and the ice crystal type composition.

| $v(D) =$ | unrimed | | moderately rimed | | densly rimed | |
|---|---|---|---|---|---|---|
| Needles | $1.10\left(1-e^{-3.07\cdot D}\right)$ | (0.30–2.7 mm) | $1.59\left(1-e^{-2.65\cdot D}\right)$ | (0.15–4 mm) | $2.04\left(1-e^{-2.06\cdot D}\right)$ | (0.15–4 mm) |
| Plates | $1.19\left(1-e^{-2.47\cdot D}\right)$ | (0.30–2.7 mm) | $1.47\left(1-e^{-2.49\cdot D}\right)$ | (0.30–3.0 mm) | $1.84\left(1-e^{-1.65\cdot D}\right)$ | (0.30–2.8 mm) |
| Dendrites | $0.87\left(1-e^{-10.31\cdot D}\right)$ | (0.30–0.8 mm) | $1.29\left(1-e^{-2.01\cdot D}\right)$ | (0.30–3.5 mm) | $1.29\left(1-e^{-2.15\cdot D}\right)$ | (0.15–3.5 mm) |
| Irreg. crystals | $1.79\left(1-e^{-1.78\cdot D}\right)$ | (0.15–5.0 mm) | $1.57\left(1-e^{-2.18\cdot D}\right)$ | (0.15–7.5 mm) | $1.70\left(1-e^{-1.79\cdot D}\right)$ | (0.15–7.0 mm) |

Table 3: *Size-fall velocity relations for aggregates consisting of different crystal types and of different riming degree. The diameter is in mm, then the fall velocity is in ms$^{-1}$.*

In respect of the riming degree, the fall velocity of snowflakes consisting of plates shows a similar behaviour as the snowflakes consisting of needles. The fall velocity of the snowflakes increases with the rising riming degree. However, snowflakes consisting of dendrites do not seem to show any dependence of the fall velocity on the riming degree. Both, for dendrites and plates, fall velocities have been fitted for all three riming regimes with the function given in Eq. 1. Fig. 3 and Table 2 summarize the diameter-fall velocity relationship of aggregates consisting mainly of either needles, plates or dendrites.

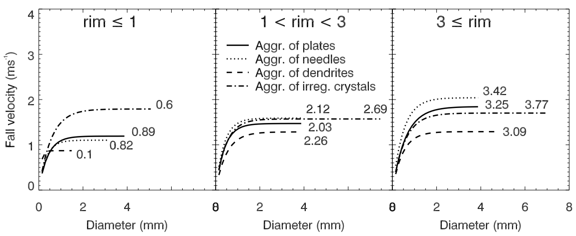


Fig. 3: *Fall velocity versus diameter for snowflakes consisting mainly of needles, plates, dendrites or irregular crystals for the three riming regimes. The numbers at the right of the lines denote the average riming degree of each crystal type and riming regime.*

### 4.2 Graupel

In 2 of the 15 cases, short episodes of graupel were observed. Four Formvar slides were found where graupel particles were the dominant crystal type and the fall velocities of these particles are shown in Fig. 4. Again, the median fall velocity for each size category is marked with a dot and the 17- and 83-percentiles are marked with thin lines. No fit has been performed since only few data are available and graupel particles are, to some extent, mixed with snowflakes of a smaller riming degree. Before a fit is performed, a procedure has to be found to separate the graupel particles from the particles with lower riming. As a comparison, the size-fall velocity relation for lump graupel from Locatelli and Hobbs (1974) is printed with a dashed line in Fig. 4.

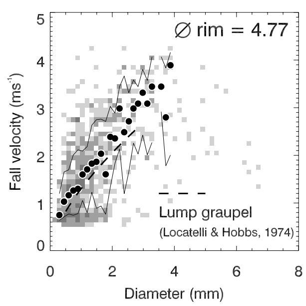


Fig. 4: *Fall velocity versus diameter for graupel particles. Median fall velocities are marked with a dot, the thin lines are the 17- and 83-percentiles.*

### 4.3 Irregular ice crystals

The fall velocities of snowflakes consisting of irregular ice crystals are shown in Fig. 5. There are obvious differences to the fall velocities of snowflakes of needles (and also of plates and dendrites). Even when unrimed, a considerable amount of small snowflakes have rather high fall velocities. The same can be observed for moderately and densly rimed snowflakes. In addition, when snowflakes are densly rimed, some of the particles are graupel particles as can be concluded from their fall velocity. However, most of the particles have fall velocities lower than 2 ms$^{-1}$ and median values as well as the fit-curves are not much different from the size-fall velocity relations of snowflakes consisting of plates, needles or dendrites.

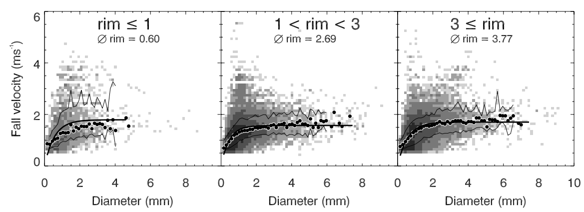


Fig. 5: *Fall velocity versus diameter for snowflakes consisting mainly of irregular ice crystals (as Fig. 2).*

## 5 AXIS RATIO

The axis ratio as used in this study is defined as

$$\mathrm{AR} = \frac{\mathrm{height}}{\mathrm{width}},$$

where height and width are the height and the width of the box enclosing the image of the hydrometeor as shown in Fig. 6. If $\mathrm{AR}<1$, snowflakes are oblate, else prolate.

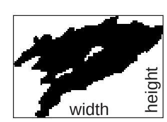


Fig. 6: *The width and the height of a hydrometeor.*

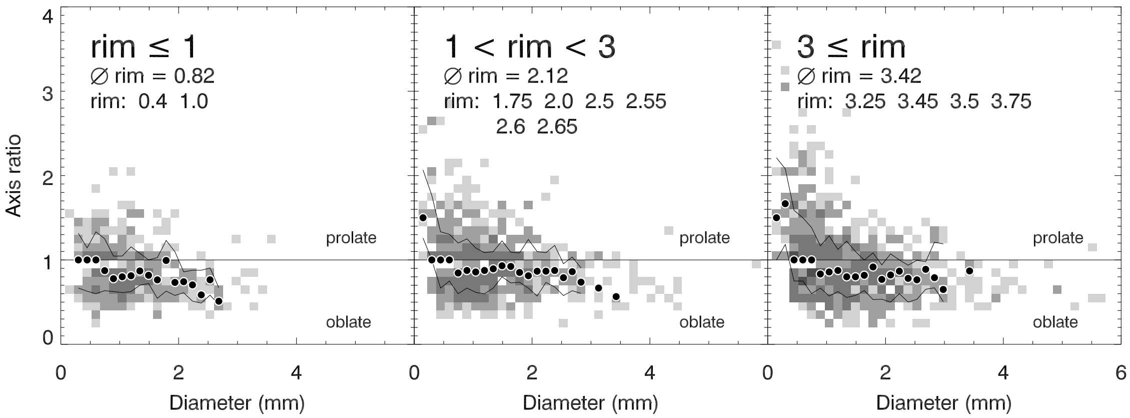


Fig. 7: *Axis ratio versus diameter for snowflakes consisting mainly of needles. The dots mark the median axis ratio for a given size category and the thin lines the 17- and 83-percentiles.*

The axis ratio of snowflakes consisting mainly of needles is shown in Fig. 7. The unrimed snowflakes have median axis ratios of 1 or less, indicating oblate snowflakes. As riming increases, more and more prolate snowflakes can be observed and the median axis ratios rise. The axis ratio versus diameter for snowflakes consisting mainly of plates and dendrites are very similar to the snowflakes of needles shown in Fig. 7. Even the snowflakes of irregular ice crystals show the same behaviour: the higher the riming the more prolate hydrometeors are measured and the higher the axis ratio. Maximum median axis ratios can be observed when graupel particles are measured. Fig. 8 shows that the axis ratio of graupel particles is close to one, as it is expected.

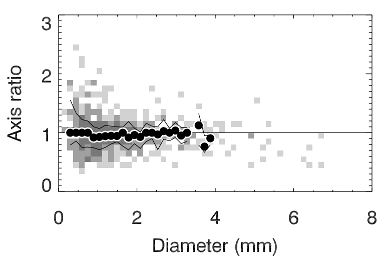


Fig. 8: *Axis ratio versus diameter for graupel particles (as Fig. 7).*

## 6 CONCLUSION

Shape and fall velocity of single snowflakes have been measured with the optical **H**ydrometeor **V**elocity and **S**ize **D**etector (HVSD). A large dataset of approx. 40'000 snowflakes was investigated. The measured fall velocity in dependence of the size of the snowflakes may be described by an exponential relationship $v(D) = a_0(1 - \exp(-a_1 D))$ where $D$ is the diameter in mm and $v$ is in ms$^{-1}$. There is a clear dependence of the fall velocity on the riming degree for all snowflakes except those consisting of dendrites. The higher the riming degree, the higher the fall velocity. The ice crystal type does not seem to have a strong influence (except dendrites) on the fall velocity of the snowflakes. Size-fall velocity relationships for a given riming regime are very similar for snowflakes consisting of needles, plates or irregular ice crystals.

The knowledge of accurate size-fall velocity relationships of snowflakes is important for precipitation process modelling but even more important is the observed variation of the fall velocity. Some precipitation processes, such as aggregation, are strongly controled by the fall velocity of the involved hydrometeors. It is important to take into account the variation of the fall velocity not only in respect to the size, riming degree and crystal type, but also in respect to the natural variability of the snowflakes when all other variables are fixed.

The axis ratio of snowflakes was investigated with respect to their size, crystal type and riming degree. There is generally a decrease of the axis ratio with increasing size. No relation of the axis ratio to the ice crystal type could be found. However, there is an increase of axis ratio with increasing riming degree with graupel particles having the largest axis ratio of approximately 1 for all sizes.

## 7 REFERENCES

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