SUPERCOOLED CLOUD TUNNEL STUDIES ON THE GROWTH OF BRANCHED

105 PLANAR SNOW CRYSTALS BELOW WATER SATURATION

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1. INTRODUCTION

Snow crystals grow by vapor diffusion and play an important role in the formation of precipitation and related atmospheric processes. Of these, the branched planar crystals are the most popular and have the greatest variety of habit. Under what conditions do the branched snow crystals grow in the atmosphere?

To address this issue, Takahashi (2014) carried out experiments with the finer-scale temperature resolution of 0.1°C using a vertical supercooled cloud tunnel that can simulate the process by which a snow crystal continuously grows while falling in a cloud. It was shown that the crystal habits are divided mainly by temperature: sector above -12.5°C, then broad-branch, then stellar, dendrite, and fern; then the pattern reverses, with dendrite, stellar, broad-branch, and finally sector below -16.1°C. Between -13.3° and -14.5°C, the sidebranch density increases with LWC. The cloud droplets contribute not only to the development of sidebranches but also to the increase in crystal thickness. The crystal diameter and mass show a maximum at -15.0°C, at which a stellar crystal, but no ferns, grows.

Although water vapor densities around natural snow crystals grown in the atmosphere are between ice saturation and a slight excess over water saturation, the above-mentioned experiments were run only at water saturation. By using a static diffusion chamber, Kobayashi (1961) and Rottner and Vali (1974) provided the comprehensive data below water saturation. It was found out and well known that crystal type was primarily determined by the magnitude of the vapor density excess: for instance, a sector, a thin, thick or a very thick plate grew as the excess decreases between −10 and −21°C. However, to understand the influence of the vapor and heat transfer by the air stream flowing past a snow crystal in the atmosphere, laboratory experiments of free-falling snow crystal growth are indispensable. Here, using a vertical supercooled cloud tunnel, we made experiments at saturation ratios less than one with respect to water. The experiments were carried out for growth time of 10 min under isothermal conditions from -12.5 to -16.5°C.

2. EXPERIMENTS

The vertical supercooled cloud tunnel used here is the same as that used in Takahashi and Fukuta (1988), Takahashi et al. (1991) and Takahashi (2014). In the tunnel, a snow crystal can be suspended freely and grown in a vertical stream of artificially generated supercooled cloud by applying aerodynamical mechanisms for horizontal stability and by continuously adjusting the upward wind speed to match that of the (generally increasing) crystal fallspeed. The tunnel was located at the Hokkaido University of Education in Sapporo, Japan, with an annual mean atmospheric pressure of about 1010 hPa.

Experiments were run for a snow crystal growth time of 10 min under isothermal condition from −12.5 to −16.5°C and with constant saturation ratios less than one with respect to water. The initial crystal shapes were plate, thick plate, or column, with maximum dimension ranging from 5 to 20 µm and of about 10 µm on average. The air temperature and the upward wind speed are measured by a thermistor and a hot-wire anemometer, respectively, and continuously monitored. The dewpoint of the air is also continuously monitored by a quartz dewpoint hygrometer. The hygrometer was calibrated with the chilled mirror hygrometer that was calibrated by a reference equipment, certified as traceable to the National Physical Laboratory, UK.

Runs having a maximum fluctuation in air temperature exceeding 0.3°C after the first minute of growth time were excluded. Sixty-two data were adopted in the following analysis. The excess vapor density with respect to ice was calculated from the air temperature and the dewpoint assuming ice

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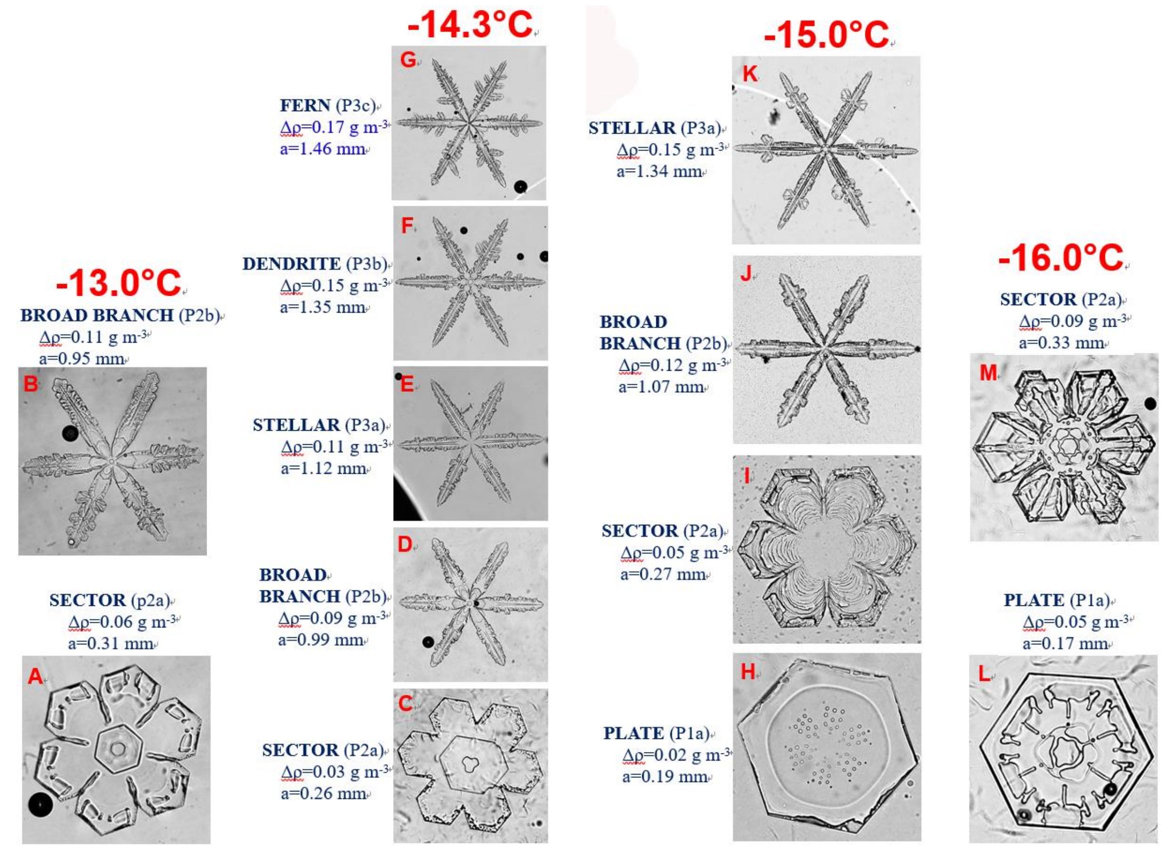

Fig. 1. Variations of crystal shape with temperature and excess vapor density after 10min of growth. The top or left of each crystal shows crystal type, excess vapor density (Δρ), and crystal diameter (a): The symbols in the parentheses are from the new classification in Kikuchi et al. (2013).

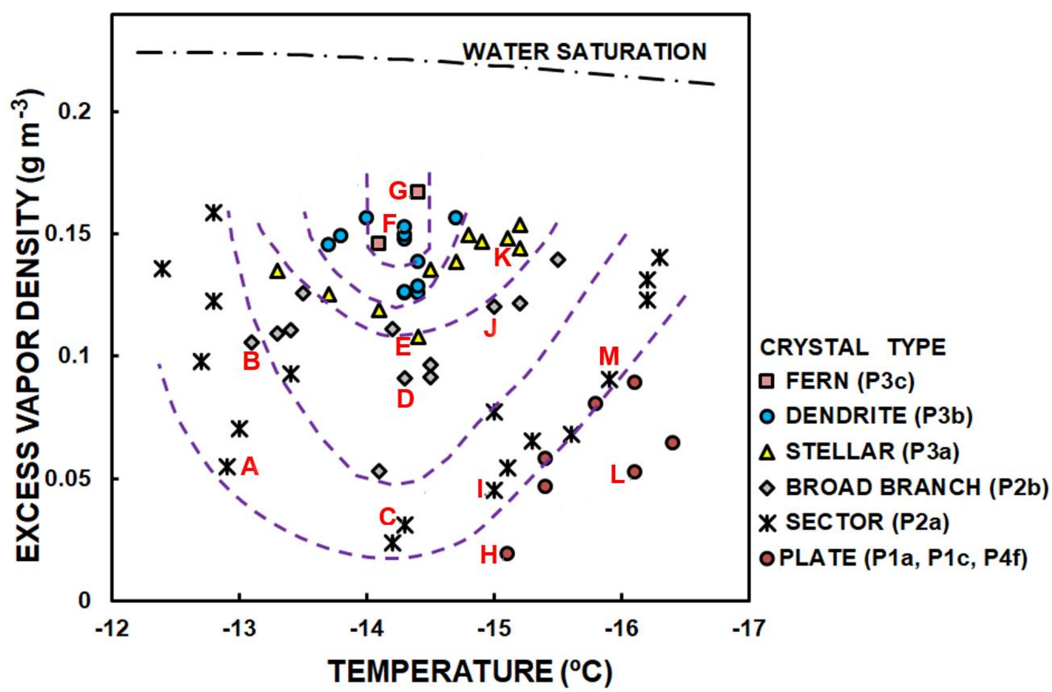

Fig. 2. Habits, temperature, and excess vapor density with respect to ice of each crystal analyzed. The crystals were grown for 10min. The each alphabetical symbol, A to M, indicates the crystal having the same symbol at upper left of each photograph in Figure 1.

saturation. This calculation was done every minute after 2 min. For fluctuations in excess vapor density, the standard deviation is 0.008 g m^{-3} on average, with a maximum of 0.018 g m^{-3}.

3. RESULTS AND DISCUSSION

Figure 1 shows the variations of snow crystal shape at four different temperatures with excess vapor density with respect to ice. The following forms occurred: fern, dendrite, stellar, broad branch, sector, and plate. The fern, dendrite, and stellar were distinguished according to the same criteria that Takahashi (2014) used: after 10 min of growth, a dendrite must have at least three crystal branches that each contain two or more side-branches, whereas a fern must have at least three branches that each contain four or more side-branches. Because the snow crystals grew in the conditions with no cloud droplet below water saturation, cloud droplets are not essential for growing sidebranches. At -14.3°C, the side-branch-rich fern habit appears; however, the side-branch-poor stellar only grew at -15.0°C. This result was in good agreement with the experimental results obtained at water saturation (Takahashi 2014). On sector branches of the crystal (I), there are several steps: the edges were round in contrast to the crystal tips were facetted. Air bubbles line up in three rows toward each prism face in the crystal (H).

The boundaries between the crystal types are shown in Fig. 2. The crystal types were dependent of excess vapor density, as well as of temperature. The crystal type regimes were roughly linearly symmetrical with the line of about -14.2°C. For example, at an excess vapor density of 0.15 g m^{-3} with respect to ice, the crystal habits were divided by temperature: sector above -12.9°C, then broad-branch, then stellar, dendrite, and fern coexisting with dendrite; then the pattern reverses, with dendrite, stellar, broad-branch, and finally sector below -16.0°C. On the other hand, as the vapor density excess increased, for a crystal.that was grown at around -14.2°C, the crystal types changed from sector, to broad branch, to stellar, to dendrite, to fern coexisting with dendrite. As broad branch, stellar, dendrite, and fern were not obtained in the static chamber experiments (Kobayashi, 1961; Rottner and Vali 1974), these branch growths may be ascribed to ventilation that brings fresh environment to the crystal surfaces in our tunnel. Conversely, in our experiments, there is no thick plate and no very thick plate, which were observed in the static chambers.

4. Conclusions

In the atmosphere, snow crystals grow while falling, which brings a fresh environment to the crystal surface, producing a feedback that affects the crystal shape and growth rate. We conducted the experiments at sub-saturation with respect to water, using a vertical supercooled cloud tunnel that can simulate the snow crystal growth process in the atmosphere.

The crystal types were dependent not only of temperature but also of excess vapor density. The crystal type regimes were roughly linearly symmetrical with the line of about -14.2°C. Crystals having fern type, dendrite type, stellar type, and broad-branch type branches were obtained, contrary to the experimental results by using static chambers (Kobayashi, 1961; Rottner and Vali 1974).

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