P1.4 LABORATORY GROWTH, SUBLIMATION, AND REGROWTH OF ICE CRYSTALS

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1. INTRODUCTION

The habit of ice crystals in the atmosphere is not only a function of temperature and ice supersaturation but also depends on nucleation mode, fall velocity, radiation conditions, and particle history. Korolev et al. (1999 and 2000) conclude from in situ observations that simple and complex polycrystalline forms are the dominant habit in the atmosphere, typically constituting between 84-97% of crystals larger than approximately 40 :m is size. This has been confirmed by Bailey and Hallett (2002a) in laboratory ice studies at at all but the lowest ice supersaturations.

Aggregation can certainly lead to the appearance of complex forms, however Bailey and Hallett (2002a and this conference) present images of individual laboratory grown polycrystals that are virtually indistinguishable from many aggregates observed in situ, some additional examples of which are shown in figure 1.

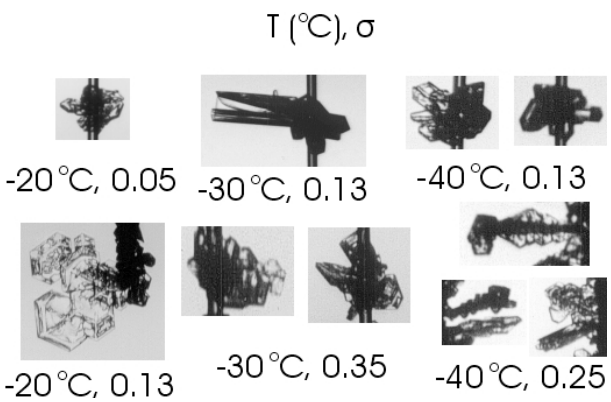

Figure 1. Complex polycrystalline forms grown in the laboratory with a static diffusion chamber that do not result from aggregation processes.

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While Bailey and Hallett observed single polycrystals with frequencies similar to those observed by Korolev et al., the higher in situ frequencies observed at times may be indicative of processes which increase the complexity of crystal populations, excluding riming and aggregation. One possible process that could accomplish this would be the fallout and sublimation of ice crystals followed by re-uptake into clouds via updrafts with subsequent regrowth. Oraltay and Hallett (1989) and Dong et al. (1984) have demonstrated that sublimation can modify crystal habit and lead to breakup and ice particle multiplication. The subsequent regrowth of these partially sublimated crystals may lead to more complex habit forms depending on whether or not the crystal has a memory of its previous orientation. To investigate this possibility, ice crystals were grown in the laboratory, partially sublimated, and then regrown in order to see if crystal orientation was modified or maintained. Both a static diffusion chamber and a dynamic diffusion chamber which can simulate fall velocity were used to investigate this possibility.

2. EXPERIMENTAL METHOD

A schematic and a detailed discussion of the static diffusion chamber used in this study can be found in Bailey and Hallett (2002, presentation 3.3, this conference). A diffusion chamber for crystal growth basically consists of two plates coated with ice at different temperatures and with a sufficient separation so as to create an environment that is supersaturated with respect to ice. In a static diffusion chamber, the growing crystals are unventilated and the supersaturation is simply a function of the height of the crystal in the chamber with respect to the two ice coated plates.

Keller and Hallett (1982) describe the dynamic diffusion chamber used in this study and investigated the influence of air velocity on the habit of ice crystals growing from the vapor. The dynamic diffusion chamber is a rectangular race track shaped chamber approximately 12 meters in total length that employs a low velocity fan to circulate air around the track at velocities up to 20 cm/s. On one side of the track, air flowing through the chamber flows over two large pans of ice that are temperature controlled and are used to condition the air with water vapor. On the opposite side are two 2 meter long diffusion chamber sections hooked end to end which consist of long rectangular plates that are approximately 25 centimeters in width with a separation of 2.5 centimeters. In one of these sections, the plates are coated with ice as with the static chamber previously described creating a supersaturated environment as a function of height between the two plates.

In both the static and dynamic cases, crystals are grown on thin glass filaments that are vertically suspended between the two plates. The dynamic diffusion chamber has a supersaturation profile as a function of height similar to that shown in Bailey and Hallett (2002, presentation 3.3, this conference). However, the effective supersaturation at the surface of a growing crystal suspended in the air flow is increased due to the ventilation provided by circulating moist air if the growth section is upstream from the other 2 meter long diffusion section which is temperature controlled but is not coated with ice. When the air flow is reversed so that air flows through the dry section before reaching the filament, the air can be made subsaturated with respect to ice with proper temperature control leading to sublimation of previously grown crystals. Another way to achieve subsaturated conditions is to maintain the moist flow orientation and to increase the air flow velocity above 20 cm/s at which time breakthrough of unregulated upstream air occurs. This distributes warmer air between the plates and at the position of a crystal on the filament, again resulting in subsaturated air at the position of the crystal.

In the static diffusion chamber, the environment is always at least saturated with respect to ice which occurs when the top and bottom plates are made isothermal. Sublimation in this case was achieved by directing a small flow of dry nitrogen onto a previously grown crystal via a small stainless steel tube inserted into the chamber from a sealed port in the chamber wall. In both the static and dynamic case, the experiments were conducted at laboratory pressure of 850 hPa (mb).

3. RESULTS

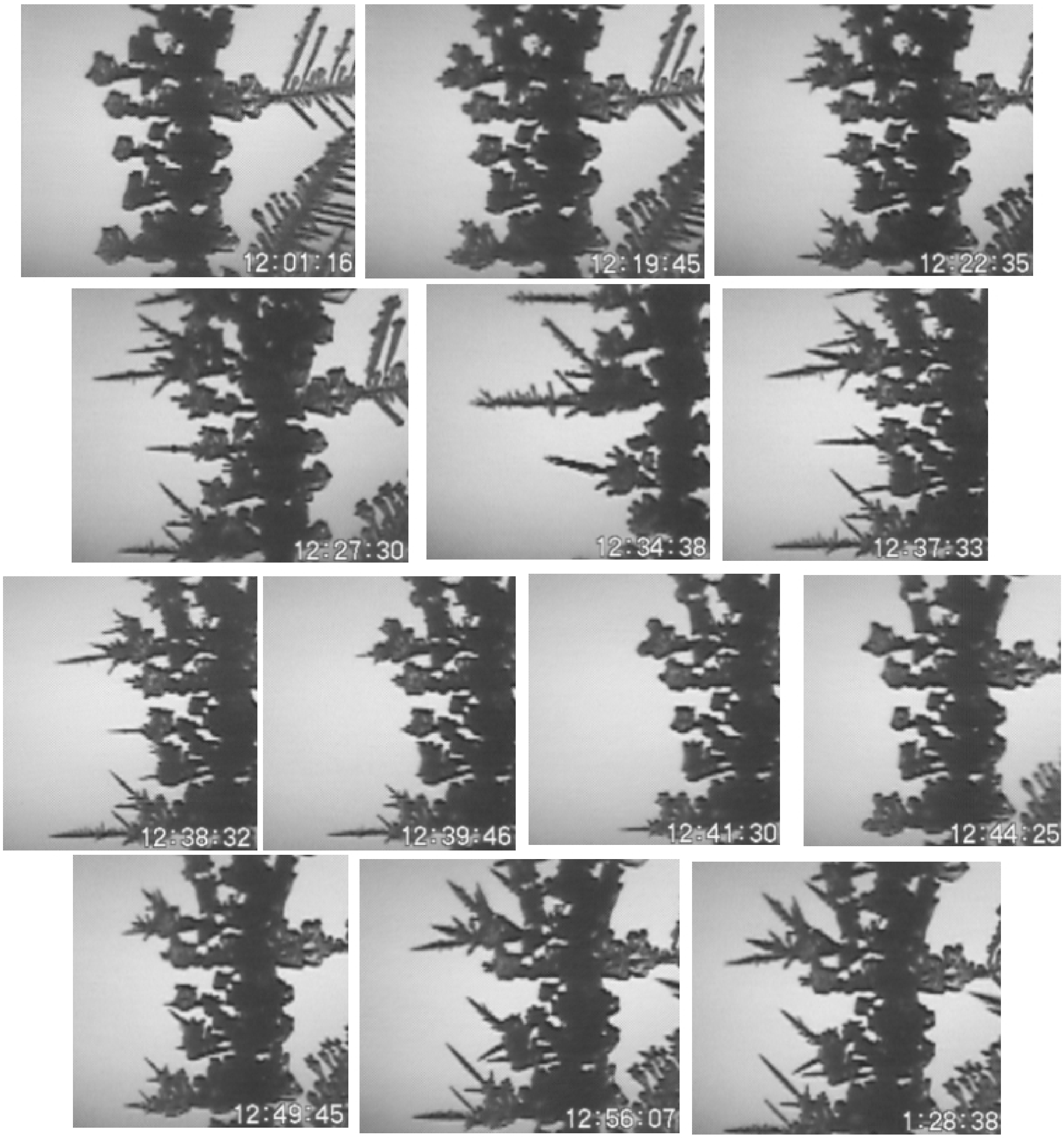
Two growth/sublimation/regrowth cases for both the static and dynamic diffusion chambers are presented in the images which follow.

In series 1, crystals were grown at a temperature of -15 $^{\circ}$C and an ice supersaturation of approximately F = 0.15. A flow velocity of 10 cm/s was sufficient to grow dendritic forms indicating supersaturation with respect to water, however, prior to recording the sequence, subsaturated air was introduced to sublimate the dendrites formed on the upstream side of the flow (dendrites on the downstream side of the filament support are visible and are shadowed by crystals on the upstream side reducing the effective supersaturation on that side of the thread which is not the region of interest). The crystals initially visible on the upstream side are sector plates which begin to sprout dendrites as growth occurs with a flow velocity of 10 cm/s in the first 5 frames. In the next 5 frames these crystals are sublimated by increasing the flow velocity above the 20 cm/s limit at which breakthrough occurs. This continued for a several minutes until the original sector plate kernel was reestablished. In the final three frames, the flow velocity is returned to a value of 10 cm/s leading to subsequent regrowth. Dendritic forms again appear but with different orientations. Since the dendritic growth region represents an extreme in terms of growth characteristics which is usually exclusive of other habit forms in laboratory experiments, it is no surprise that dendrites again appear. However a change in orientation of the branches has occurred which is likely due to minute surface structure changes of the sector plate kernel that were influenced by sublimation.

In series 2, crystals were initially grown at a temperature of approximately -8 $^{\circ}$C and an ice supersaturation of approximately F = 0.12 a columnar/sheath growth regime which is also supersaturated with respect to water. Flow velocity was set at 10 cm/s. Thick sheaths initially grown under moist flow conditions were then rotated to face a subsaturated reversed flow. After sublimating for several minutes, the flow was reversed again to provide moist flow conditions and the crystals were rotated to face this flow. The process was repeated three times as seen in the images. Sheath types reappeared each time but again with different and typically more complex orientations.

Series 3 was obtained with the static diffusion at -10 $^{\circ}$C and an ice supersaturation of approximately F = 0.12. This environment was also supersaturated with respect to water which results in mixed habits of cup-like crystals with extensive hopper patterns, sheaths, bundles of sheaths, scrolls and other complex forms. In the static diffusion chamber, the vapor field is symmetric with respect to the filament support contrary to the ventilated conditions of the dynamic diffusion chamber. However, defects in individual crystals lead to habit forms with very different characteristics as discussed by Hallett et al. (2002) so that uniformity

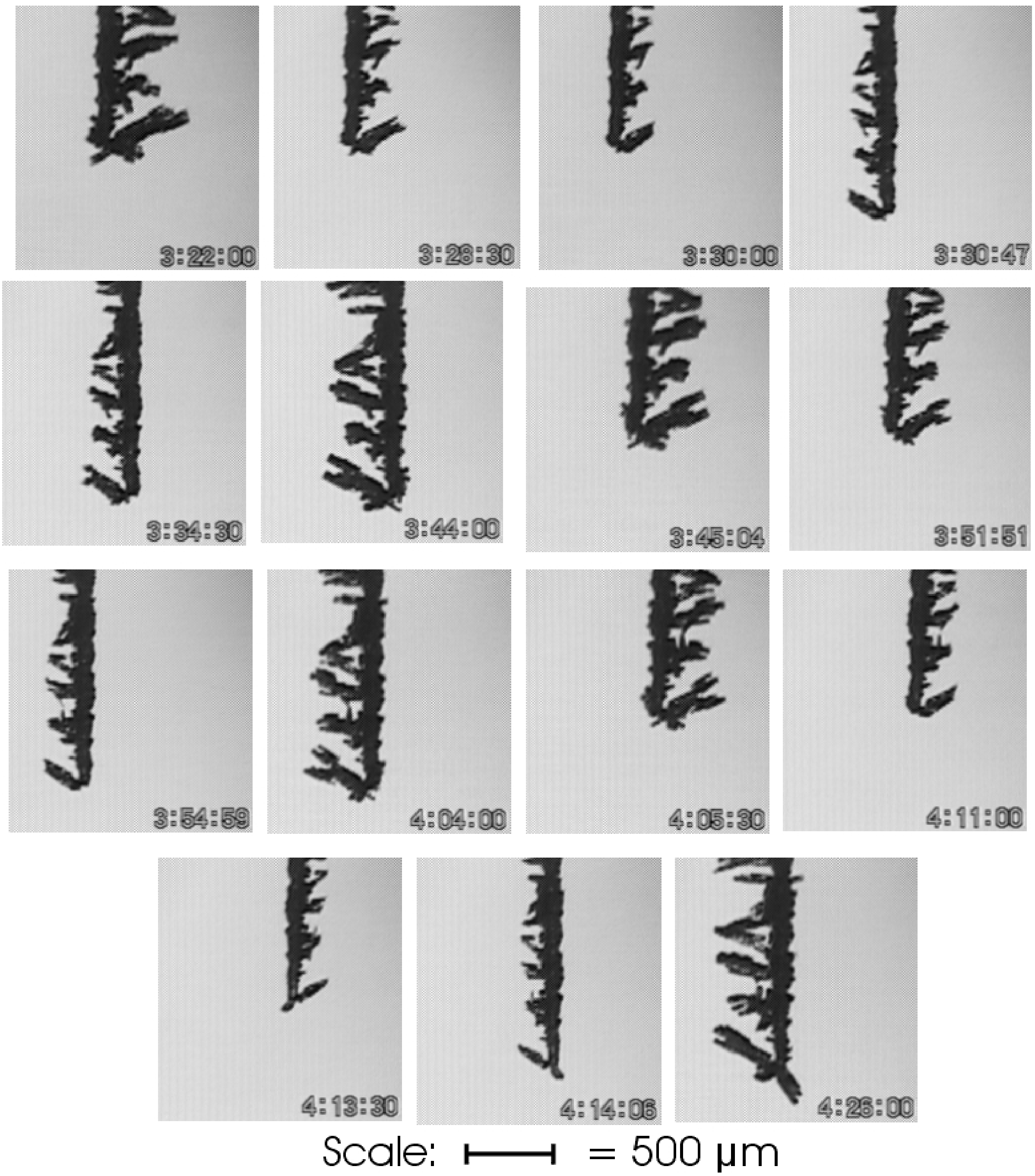
Series 1



Scale: ⊢—⊣ = 500 µm

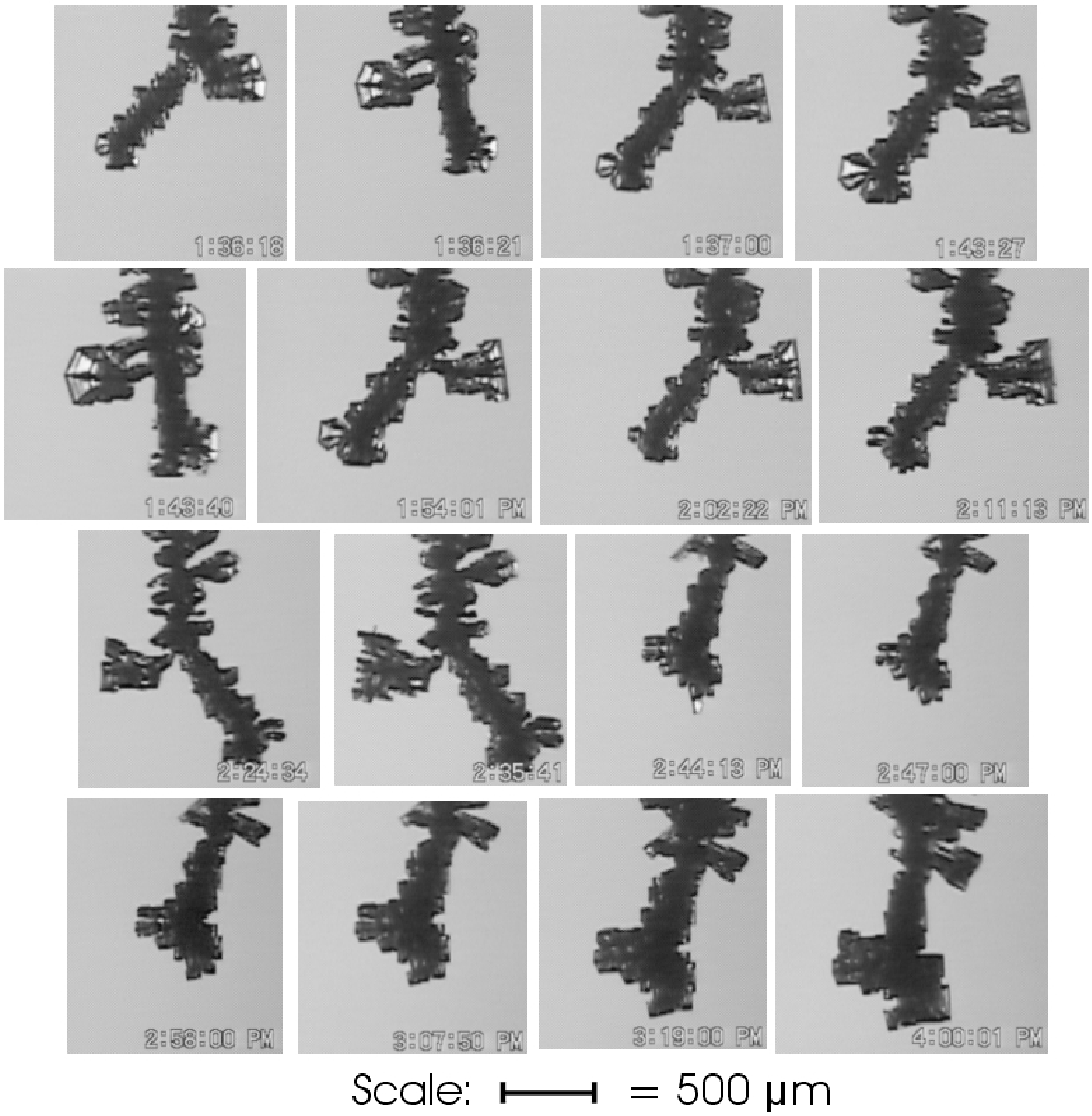
Series 1. Crystals grown, sublimated and regrown in a dynamic diffusion chamber at a temperature of -15 °C, an ice supersaturation of approximately F = 0.15, and a flow velocity of 10 cm/s.

Series 2



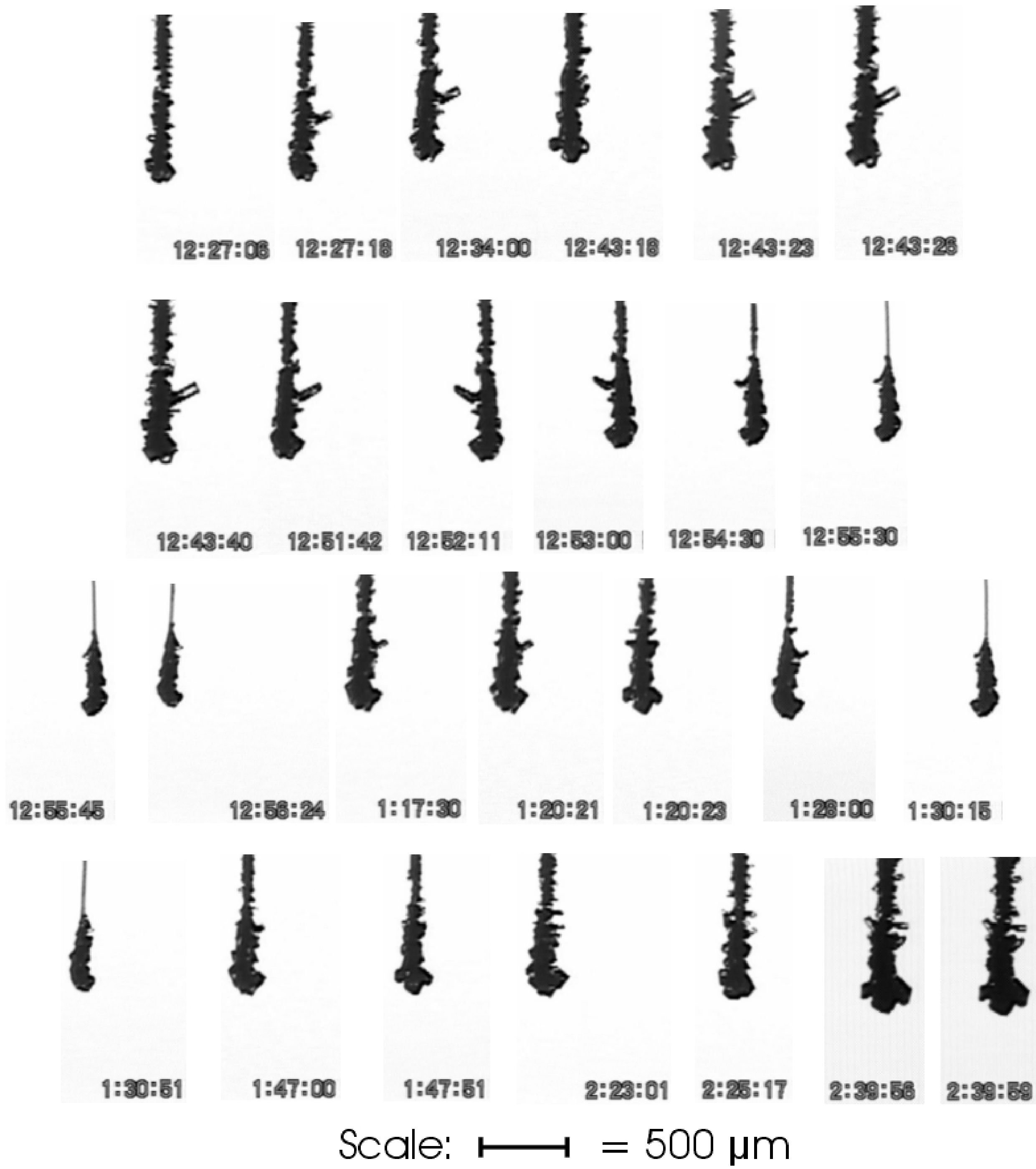
Series 2. Crystals grown, sublimated and regrown in a dynamic diffusion chamber at a temperature of -8 °C, an ice supersaturation of approximately F = 0.12, and a flow velocity of 10 cm/s.

Series 3



Series 3. Crystals grown, sublimated and regrown in a static diffusion chamber at a temperature of -10 ^{o}C and an ice supersaturation of approximately F = 0.12.

Series4



Series 4. Crystals grown, sublimated and regrown in a static diffusion chamber at a temperature of -10 °C and an ice supersaturation of approximately F = 0.06.

is not expected or observed. In this sequence, the filament support was rotated so that crystals at various positions were faced toward the dry nitrogen flow which caused sublimation to occur. Two complete cycles with a final growth sequence are shown. Once again a pronounce change in crystal habit and orientation are observed.

The final set of images, series 4, show crystals growing in the static diffusion chamber at a temperature of approximately -10 °C and an ice supersaturation of F = 0.06 which is subsaturated with respect to water. This is a habit regime where thick plates are the most common form observed but in which columns may occasionally appear. In this sequence focus should be placed on the assemblage of thick plates growing from the bottom of the filament and the column growing from the side approximately 500 :m above this point. In the first seven images, the column and assemblage of plates at the tip is observed to grow. In the next seven images partial sublimation occurs followed by three images showing subsequent regrowth. Additional sublimation in the next three frames sublimates the column to its base but not the assemblage at the tip of the filament. The column does not appear in the final images but several smaller columns at different positions in the vicinity of the original column are apparent. The assemblage of thick plates at the tip was essentially regenerated each time though with modified facets and additional faceted components that are not visible at the resolution of the images. A cluster of plates of this type would be subject to vapor competition amongst the neighboring component plates that probably helps to maintain the habit through the cyclical process described while spatially extended crystals like columns are more strongly effected.

4. CONCLUSION

Growth, sublimation, and regrowth of ice crystals have been investigated in the laboratory with both a static and a dynamic diffusion chamber. The results show that such a process modifies and changes the habit in complex ways that appear to indicate that crystals do not retain memory of their previous habits or orientations under conditions ranging from moderate ice supersaturation to supersaturations at or above water saturation. From these results it may be concluded that the extent of modification due to this cyclical process is related to the degree of supersaturation, subsaturation and the duration of these conditions. Growth, sublimation, and regrowth of ice crystals under conditions of low ice supersaturation and subsaturation probably do not lead to the degree of habit modification observed in this study though some modification is likely.

ACKNOWLEDGEMENTS

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