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Observation and Characterization of Cirrus-Like Ice Crystals Using ESEM

Mitch Benning
mbenning@pugetsound.edu

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Mitch Benning '13
Advisor: Steven Neshyba

Background

Cirrus cloud ice crystals are of interest for study because of their relevance in climate modeling, particularly in the way that incoming light from the sun scatters upon striking them. By understanding this mechanism better, more accurate climate models can be built. Recent experimental research has elaborated on the previous smooth model of ice crystal growth by adding trans-prismatic strands (surface roughness) to account for the discrepancy between theoretical scattering and observed scattering. By using an SEM to grow ice crystals and Fourier transforms for analysis, a deeper understanding of growth is hoped to be understood.

Experimental

A reservoir of ice was placed inside of the SEM, a coldstage was turned on as the pressure was pumped down and the backscatter detector imaged the stage (Figure 1). Ice crystals grew on the stage at various pressures as long as the temperature was low enough (Figure 2.) By keeping the temperature low enough to prevent ablation for periods of time, studying the habit and mesoscopic properties of cirrus ice crystals became much easier.

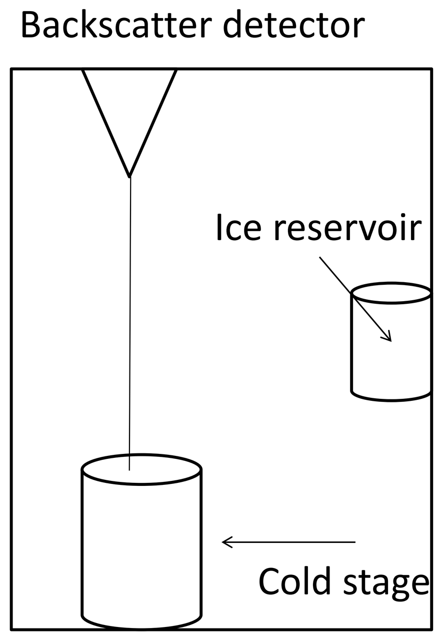

Figure 1. Experimental setup inside of SEM.

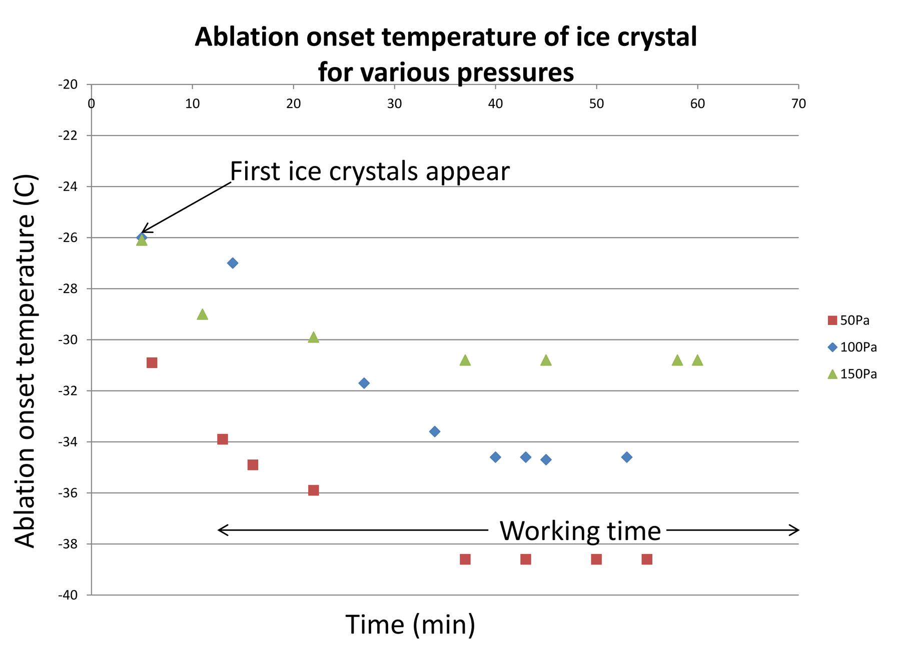

Figure 2. Ablation temperature over time for different pressures.

Acknowledgements and References

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1. Pfalzgraff, W.C., Scanning electron microscopy and molecular dynamics of surfaces of growing and ablating hexagonal ice crystals. *Atmospheric Chemistry and Physics.* **2010**, 10, 1-9
2. Bales, G.S, Zangwill, A, Morphological instability of a terrace edge during step-flow growth. *American Physical Society.* **1990**, 41, 5500-5508

Results

The usual ice crystal grown in the SEM is hexagonal and has six prismatic facets, two basal facets and multiple pyramidal facets as seen in Figure 3. In addition, as previously observed by Pfalzgraff et al., the mesoscopic properties of cirrus-like ice crystals contain surface roughness on their prismatic surface only. The rough structures formed on the crystal are called trans-prismatic strands and help account for the light scattering discrepancy.

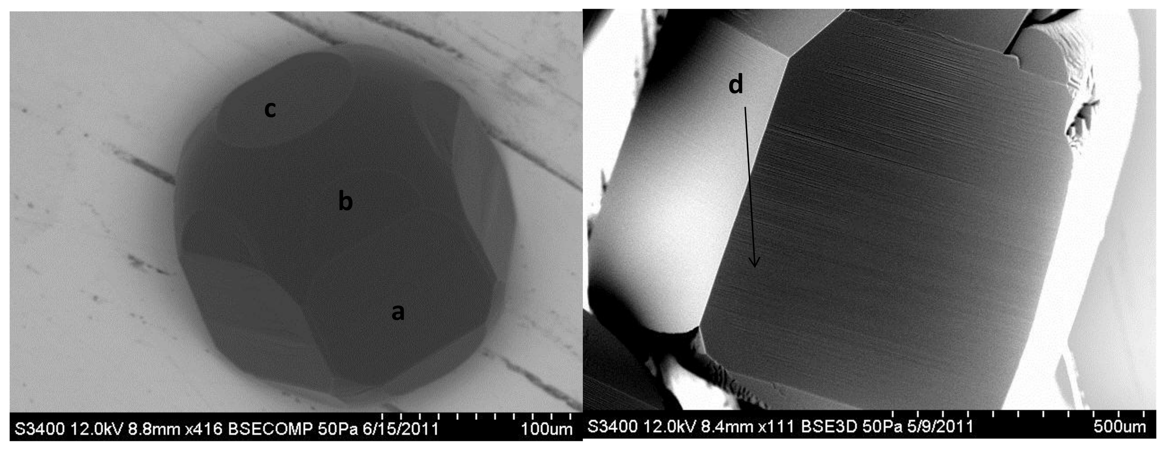

Figure 3. Left: Early growth of hexagonal ice crystal showing prismatic facet (a), pyramidal facet (b), and basal facet (c). Right: Late growth of hexagonal ice crystal showing trans-prismatic strands (d).

Upon changing the ambient pressure in the SEM, the strands appear to separate more (Figure 4.). This is what led into the main focus of research, whether the spacing of the step flow growth varies with pressure.

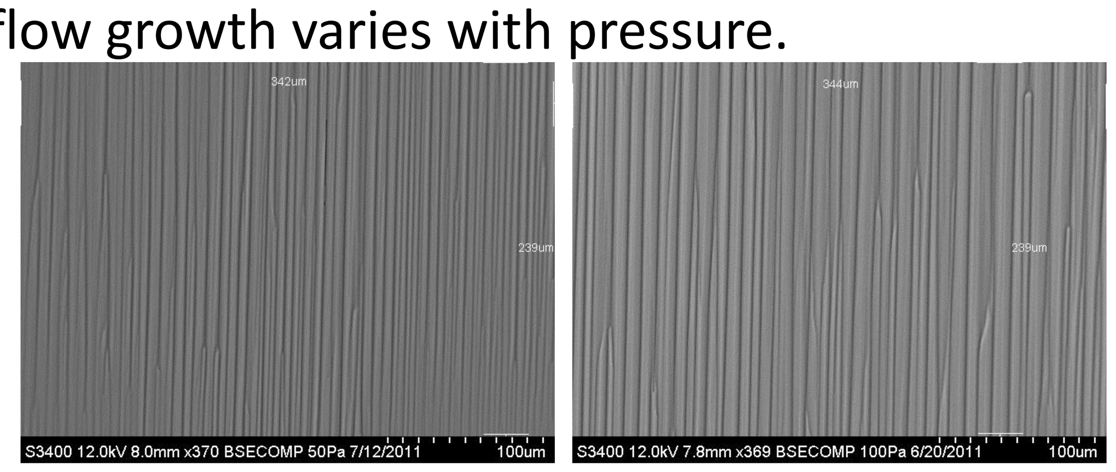

Figure 4. Prismatic surface at 50Pa and 100Pa showing a slight increase in strand spacing as pressure increases.

$$\nu_{max} = \frac{\left[\frac{4}{3}\left(1-\frac{\Gamma}{x_s\tau(F-F_{eq})}\right)\right]^{1/2}}{x_s} \quad (1)$$

$$\nu_{max} \approx \left[1-\frac{A}{(F-F_{eq})}\right]^{1/2} \quad (2)$$

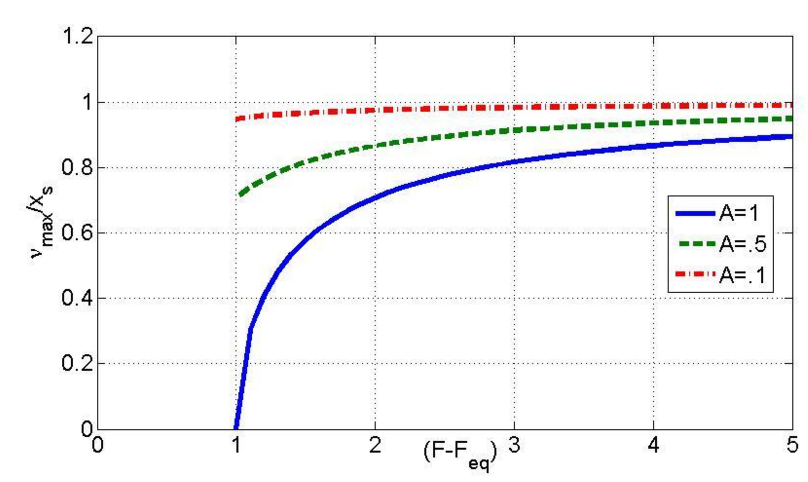

Figure 5. Plot of F-F_{eq} vs $\nu_{max}/\ x_s$ to illustrate predicted values of ν_{max}

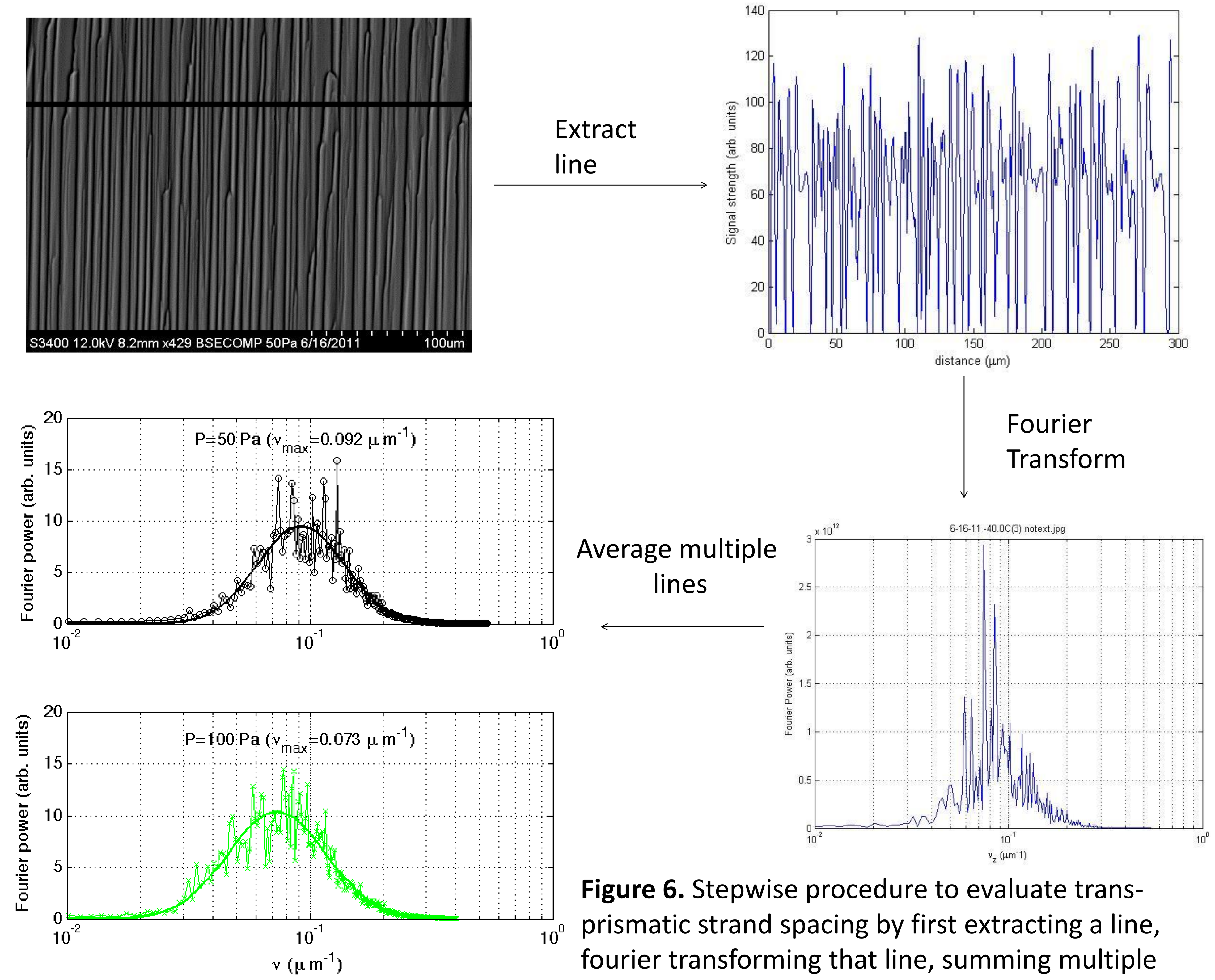

Figure 6. Stepwise procedure to evaluate trans-prismatic strand spacing by first extracting a line, fourier transforming that line, summing multiple lines in multiple pictures at the same pressure, and then comparing the results with pictures from a different pressure.

Discussion

From our analysis, it appears that strand spacing is affected by the ambient pressure. Theoretical work on the step flow theory of how ice grows using linear stability analysis gives equations but not numerical values for many defining characteristics on the surface of an ice crystal. (1-2) Pfalzgraff et al estimated the value of x_s to be approximately 0.01µm and our experiment estimates ν_{max} to be approximately 0.1 μm^{-1}, which satisfies the requirement that $(x_s)(\nu_{max}) \ll 1$ for (1). In order to study the difference between varying pressures, we examined the spacing of the trans-prismatic strands through multiple Fourier transforms of multiple images at each pressure. Upon completing the analysis (Figure 6.), a significant difference in the spacing of the strands was observed. This gives rise to the idea that with increasing pressure ν_{max} (the wavenumber of the strands) decreases and thus λ_{max}(the spacing between the strands) increases. Upon examining the theory and simplifying (1) to obtain (2), it is evident that with increasing values of $F-F_{eq}$ (which corresponds to increasing pressure), the value of ν_{max} will increase, as is shown in Figure 5. However, our results directly contradict these predictions, with ν_{max} increasing with decreasing pressure.

Conclusions

It is possible to grow ice crystals that exhibit mesoscopic properties at a higher pressure than previously thought.

This work has generated experimental evidence that ν_{max} decreases with increasing pressure, contrary to current step-flow theory.

Upon completion of Fourier analysis, the distribution of ν_{max} is log-normal.