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VP-SEM Investigation of 3-D Surface Morphology in Cirrus-like Ice Crystals
Nick Butterfield and Steven Neshyba

Introduction:
Cirrus clouds play an important role in the earth’s radiative budget due to their scattering properties. One important factor in scattering from cirrus clouds is the surface morphology (i.e. roughness) of cirrus ice crystals, as can be seen in the images below.

Experimental Setup:
A Deben Ultra-Cool Stage MK3 version Peltier cooling element is inserted into the SEM chamber along with a 4 mL ice reservoir. The chamber operates at low pressure conditions (<1 – 250 Pa), and the ice reservoir maintains that pressure as water vapor. By decreasing the temperature of the cold stage below the equilibrium water vapor pressure, the vapor nucleates onto the copper stub, where it is imaged using the SEM backscatter electron (BSE) detector.

Experimental Methods:

Once the components are found, a basic surface can be constructed by calculating the surface height at each point from the normal vector at the previous point:
\[ z_i = z_{i-1} - \frac{n_x(1-o_j)}{n_z(1-o_j)} \cdot d \]

3D Reconstruction Methods:
A 3D image can be constructed from the four bitmap images captured from the BSE detector using a generalization of parallax. A 3D reconstruction program (3D image Viewer v. 1.01 by Denshi Kougaku Kenkyuso Company) was supplied along with the SEM, but when applied to a surface of known morphologies, it was unable to accurately reconstruct all the features. A new program was needed to analyze the images.

Various algorithms exist for graphic design that generate an image from an object; we needed to work backwards from the captured images to create the object. We selected the Blinn-Phong algorithm due to its simplicity and effectiveness.

The Blinn-Phong equation² is used to calculate the brightness of a point on the surface of an object:
\[ c = v \cdot c_i(h \cdot n)^\alpha + c_o \]

Where \( c \) is the observed light intensity, \( c_i \) is the incident light intensity, \( n \) is the surface normal vector, \( h \) is the half vector between the light source and the detector, and \( p \) is the Blinn-Phong exponent. The parameters \( c_o \) and \( v \) are the base brightness and contrast settings for the four images.

Conclusions:
- One success of this summer work is the large body of ice crystal data collected; this data shows qualitative roughness trends at various pressures and temperatures.
- In order to improve the quantitative value of this data, I will continue to develop the Python reconstruction code as the subject of a thesis.

Further Work:
The major problems yet to be addressed are:
- Solutions of \( p, v, c_o \), and \( c_i \) that generate an accurate surface are not unique.
- The reconstruction technique is not optimized to reduce error using all the available data.

References: