Snow Crystal Habits and the Effects of Riming

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ABTRACT

Snow comes in many shapes and sizes. In addition to simply being beautiful, this variability often is correlated with the environment in which a particular snowflake forms. For this reason, the careful observer can learn much about how variables such as temperature affect crystal growth and formation. In addition, if one knows the chemical composition of such a hydrometeor, even more may be said about the microphysical processes that likely led to its formation. This study focuses on one snowstorm that affected the Storm Peak Laboratory site in Steamboat Springs, Colorado on 1 April 2010. Both the habit distribution and chemical properties of snow that fell at the lab site are analyzed. The primary findings include a surprisingly high frequency of the irregular crystal habit and an increasing acidity trend in precipitation throughout the storm's duration.

1. Introduction

The study of snow crystal habits has a long history. In 1966, Magono and Lee published their findings which attempted to classify snow crystal habits based on temperature and supersaturation. They collected many in situ samples of snow crystals to make generalizations about the conditions under which certain crystal types would form. Other studies have used laboratory equipment to try to reproduce these findings. Pruppacher and Klett (1997) published their own version of the supersaturation vs. temperature graph which incorporated the use of laboratory equipment to specify precise environmental conditions. In the years between these two studies, there have been dozens of other versions of the crystal habit graph; however, few studies have more thoroughly analyzed the issue than a recent paper by Hallett and Bailey (2009). Their studies have found that many previous studies with columnar behavior beginning at -20 C were in error since they did not take into account the modification of habit distribution due to sedimentation. They are also one of the first to publish a three-dimensional graphic which includes crystal growth rate on a z-axis. Another useful graphic is the traditional two-dimensional plot that includes actual samples of crystals grown (Fig. 1).

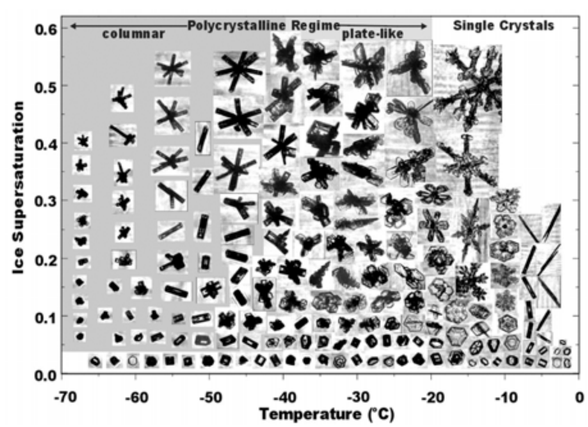


FIG. 1. Snow habit diagram with examples of actual crystals (adapted from Hallett and Bailey 2009).

Due to the short time period tested and limited data available, this study did not attempt to reproduce any such habit diagram, but rather focused the on the distribution of habits for one storm system to connect environmental temperature to crystal type. The value of this comparison is enhanced by previous similar research done by Hester Leung (2005) who analyzed two storm systems in late March. The hypothesis was that a similar distribution would be found since the mean flow direction, west-northwesterly, was similar in all three cases.

A secondary objective of this study was to characterize snowfall during the 1 April 2010 storm based on its chemical characteristics. The second hypothesis was that dendrites would have a lower pH due to the increased amount of riming from more acidic cloud droplets. Although the quantitative amount of riming was later found to be impossible to determine with equipment available at Storm Peak Lab (SPL) the pH findings are nevertheless illustrative of important microphysical effects.

2. Methods

With its unique location on top of one of the tallest mountains in the Park Range (Mt. Werner, 10565 ft), SPL provides valuable information with regard to cloud physics and cloud-aerosol chemistry. Clouds often cover the summit where coincident, in situ measurements of both cloud and precipitation can be made.

A cloud sieve was used to collect cloud droplets during the 1 April 2010 storm. The chemically inert nylon sieve had a grid spacing of approximately 0.6 cm and was placed on the roof of SPL during seven different time periods (Fig. 2). The sieve was allowed to collect rime for approximately 45 minutes for each experiment, thus allowing enough rime to collect to be melted and stored in non-reactive bags. Precipitation samples were collected from low-wind areas around the lab during the same seven time periods allowing for comparison between cloud and precipitation. These samples were also melted and stored in non-reactive plastic bags.

Between collection periods, multiple photos were taken with a Canon PowerShot A560 digital camera. Later, this data was analyzed and hundreds of individual frozen hydrometeors were classified. Unfortunately, only a rough classification of crystal types was possible with this camera which had limited zoom ability.

When sample collection concluded near 0120 UTC, an Oakton pH 110 series meter was used to measure the pH of each sample. The meter had automatic temperature calibration and was calibrated with buffer pH solutions every four measurements to ensure quality data.

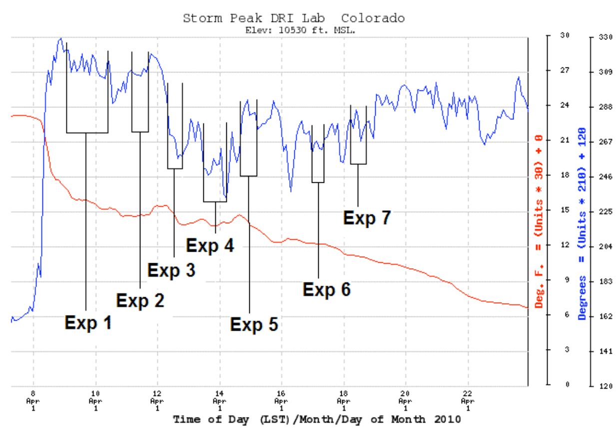
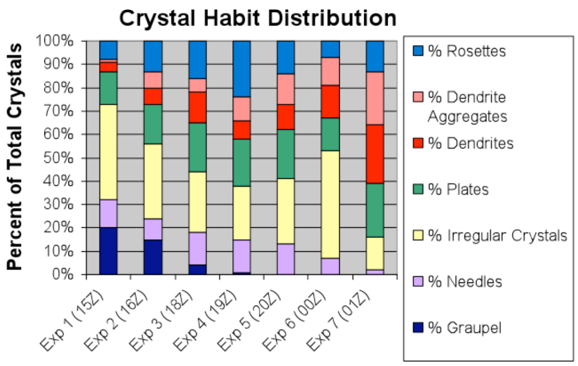


FIG. 2. Mean wind direction (blue) and temperature (red) highlighting the time periods sampled. For reference, experiment 1 starts at 9:00 AM local time (1500 UTC) and experiment 7 ends at 7:20 PM (0120 UTC).

3. Results

A number of interesting trends can be seen in the classification data (Fig. 3). The first trend is the large percentage of irregular crystals found at all time periods, with the most being 41% found during experiment 1. A second trend is the quick decrease in graupel within hours of precipitation initiation. The rosette crystal type showed no definite trend, but the amount of dendrites and dendrite aggregates increased throughout the day as temperatures fell.



The chemical testing also shows a number of trends (Fig. 4). The most obvious is the cloud's more acidic nature at all times. Second, the pH of precipitation slowly fell throughout the storm's duration. On the other hand, the cloud pH remained fairly constant with only minor variations. This resulted in precipitation pH approaching cloud pH as time progressed.

4. Discussion

The results of the snow crystal habit distribution were not entirely surprising, and did resemble previous work by Leung as hypothesized. The most unexpected finding was the large percentage of irregular crystals found in the sampling. If one were to look at many previous studies regarding snow habit classification, there is rarely a place for irregular habits in the common temperature vs. supersaturation diagrams. Perhaps even more stunning is the fact that no numerical weather prediction models have irregular crystals included in their snow parameters. This means that the models are missing a very important mode of snow crystal formation, and may be improved by the addition of such a representation.

The increasing presence of dendrites may be explained by the falling temperatures seen in Fig. 1. The cooling clouds seemed to reach a temperature where they could more efficiently support dendritic growth. The disappearance of graupel at later times was also correlated with temperature falls. The most likely explanation was initially stronger, warmer updrafts disappeared as time went on, hence preventing any melting and refreezing of precipitation during the later experiments.

The cloud pH vs. precipitation pH graph (Fig. 4) confirms a commonly known finding: cloud pH is noticeably more acidic than precipitation pH. This occurs because a cloud droplet has a much higher dissolved acidic CCN to water ratio than precipitation. As mentioned earlier, no explicit quantitative riming measurements we able to be taken, but it is plausible that the effects of riming may have caused the precipitation pH to drop over time. As more dendrites form, there is a higher chance of cloud droplets being accumulated on the surface of the large dendrites. This could cause the pH to drop as observed.

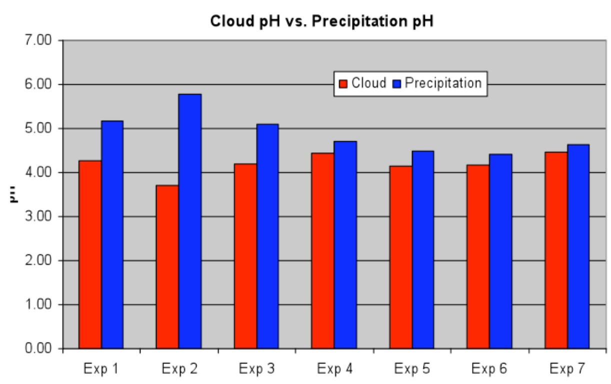


FIG. 4. Cloud vs. precipitation pH for each experiment.

5. Conclusions

The nearly infinite amount of individual snowflake shapes can be grouped into several broad categories. Each of these categories has a preferred environment in which they form. Many researchers have attempted to accurately characterize this variability using the atmospheric variables of temperature and supersaturation. In a study of an April snowstorm at SPL in Steamboat Springs, CO, the primary mode of precipitation was found to be the irregular crystal, a form numerical weather prediction is still attempting to incorporate into models. The chemical identity of precipitation is different from that of the cloud in which it forms. The pH of precipitation is more neutral than the acidic cloud, but not by a fixed amount. Processes such as riming can affect the pH of precipitation to such an extent that there is little difference between cloud and precipitation pH.

There is much room for future work in the area of microphysical chemistry. With higher sensitivity equipment and more powerful digital cameras, it may be possible for future studies to achieve a more quantitative estimate of the riming effect on precipitation. In addition, numerical weather model parameterizations for irregular crystal habits may be tested to check for forecast improvement in regions such as SPL, where the irregular crystal mode is common.

6. References

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