P12A.5

SNOW STUDY AT CARE

E. Jung[1]*, I. Zawadzki[1], G. Lee[2]
[1]McGill University, Montreal, QC, Canada
[2]National Center for Atmospheric Research, Boulder CO

1. INTRODUCTION

Winter precipitation begins with ice crystals building up by heterogeneous nucleation and growth by deposition. These ice crystals then continue to grow into snowflakes by aggregation and riming. The aggregation of ice crystals is one of the fundamental processes in the growth of precipitation particles, involving, first, collision of the crystals and, then, adhesion. Aggregation growth process allow the crystals produced by deposition to continue to grow larger, and, what is more, the larger aggregates in particular play an important role in radar meteorology as the energy backscattered by a particle is determined by the size of the particle. Moreover, snow is commonly observed to fall as complex particles rather than pristine crystals. It is not clear whether this is due to growth by deposition, in which the habit of growth changes during fall as result of changes in particle orientation and of environmental conditions, to aggregation or to both processes.

It is widely accepted that growth by aggregation occurs at frequency increasing with temperature and is maximized when ice crystals of different shapes and terminal velocities collide in atmospheric layers of temperatures between 0 and -10˚C. On the other hand, some aircraft observations (e.g., Heymsfield et al., 2002) measured relatively large particles, ranging from 2 mm to 6 mm, at cloud tops even at temperatures as cold as -50˚C. The primary mechanism involved in aggregation growth at cold temperatures has yet to be determined.

2. DATA

The CALIPSO/CloudSat satellite instruments were successfully launched by NASA from Vandenberg Air Force Base, Calif. in April 2006, on a mission to uncover the inner secrets of clouds and aerosols. In order to provide comprehensive information on cloud and precipitation from the ground to match the satellite measurements, two enhanced measurement sites have been maintained in the regions of the Great Lakes of Canada at the Centre for Atmospheric Research Experiments (CARE) and in the high Arctic on Ellesmere Island. C3VP (Canadian CALIPSO/CloudSat Validation Project) will also evaluate the quality of the CALIPSO/CloudSat products as they are applied to Canadian climate, with a focus on stratiform cold-season cloud systems (Hudak et al., 2007). Data used in this study were obtained at the CARE site between 2005 and 2006 with a HVSD (Hydrometeor Velocity and Shape Detector) and the VertiX (vertically pointing X-band) radar. The HVSD provides information on the shapes, sizes and fall velocities of freely falling precipitation particles (Barthazy et al., 2004), while VertiX measures reflectivity and velocity structures with high temporal and spatial resolution.

3. RESULTS

Fabry and Zawadzki (1995) first used the gradient of reflectivity, $-d(\ln Z_e)/dh$, to show the snow growth rate by deposition in their long-term radar observation of the melting layer. Zawadzki et al. (2007) calculated a long-term average of the snow growth rate using data from the McGill S-band radar. They showed that the average snow growth is approximately 4-5 dB/km in regions around -15°C where deposition is favored. S-band radar has relatively coarse resolution (1 km range resolution and 1˚ beam with) compared with the vertically ponting X-band radar (VertiX) used here with 37.5 m

---

* Corresponding author address: Eunsil Jung, McGill Univ., Dept. of Atmospheric and Oceanic Sciences, Montreal, QC, Canada;
e-mail:eunsil.jung@mail.mcgill.ca

vertical resolution and 2° beam width. Thus, Vertix data are used here for the calculation of snow growth rate. Some Doppler spectra observed during a 20 minute time period by VertiX are illustrated in Fig. 1. Time series of reflectivity and Doppler velocity during this time period are illustrated in Figure 2 where an average snow growth rate of 10 dB/km is seen.

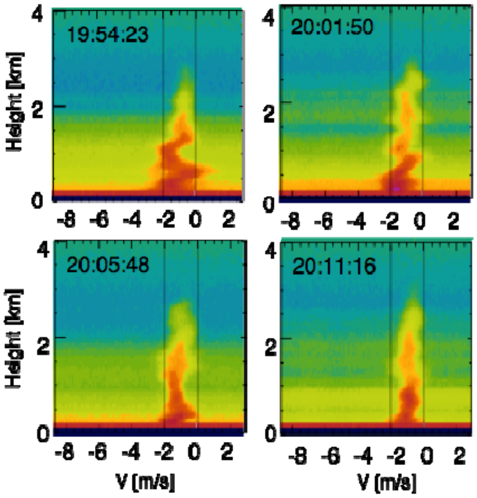

Figure 1: *Doppler spectra widths for the period of 19:50 and 20:10 on 24th Nov. 2005 measured by the McGill VertiX.*

This is an unusually rapid growth rate when compared to the more average observed rate of snow growth, 4 to 5 dB/km, for stratiform precipitation (Zawadzki et al., 2007). The Doppler spectra in Fig. 1 show broad widths as well as zigzag patterns, indicating the existence of strong turbulence at all scales. An interesting question is whether turbulence may be responsible for the rapid reflectivity growth with fallen height.

Reflectivity increases as hydrometeors fall, implying no sublimation on the average. Average Doppler downward velocity also increases as height decreases to about -1.3m/s at 500m, then remains constant.

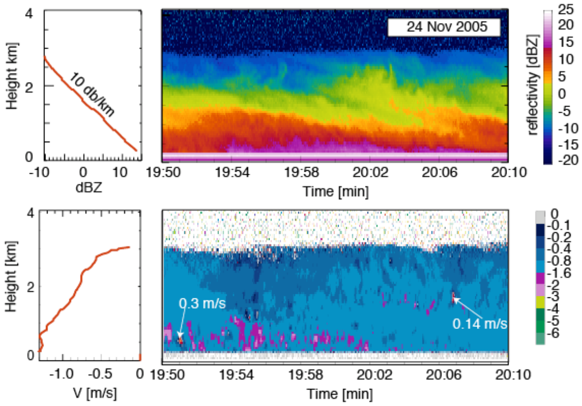

Figure 2: *Height time section of reflectivity (upper) and Doppler velocity (lower), together with their mean profiles measured by the McGill vertically pointing X-band radar on 24th Nov. 2005 between 19:50 and 21:10 UTC at the CARE site.*

During this period, there are areas of positive Doppler velocity (indicated by arrows) implying upward motion (0.3m/s and 0.14m/s). Since snow terminal fall velocity is close to 1 m/s this indicates very strong vertical air motions, unusual for stratiform precipitation. Thus, saturated ascending air may become supersaturated and provide an environment for liquid water generation and possibly leading to increased growth rate by riming.

The HVSD measured velocity distribution for snow particles of diameters between 2 and 3 mm, for the same period, is illustrated in Figure 3.

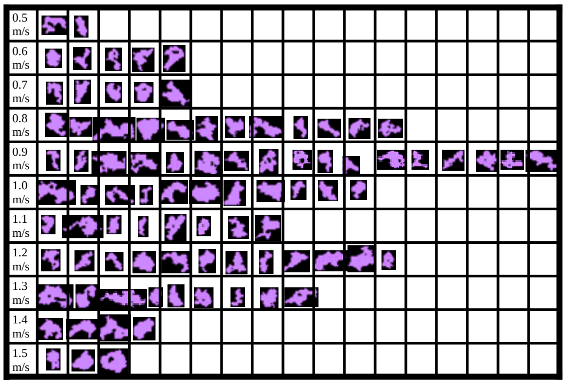

Figure 3: *The velocity distribution of snowflake particles with diameters of 2–3 mm. Particles were collected on 24th Nov. 2005 between 19:50 and 20:10 UTC at the CARE site.*

Figure 4 presents a *v*-D scatter plot with means and standard deviations for each size interval (upper), collected by the HVSD on 24th Nov. 2005 between 19:50 and 21:23 UTC at the CARE site, together with sounding profiles (lower) obtained during aircraft ascents/descents. The mean velocity is approximately 1.0 m/s with a wide range of velocity variation, indicating the importance of stochastic processes in snow growth, and widely different particle shapes. Images recorded by the HVSD revealed the particles to be aggregates with holes and rough surfaces.

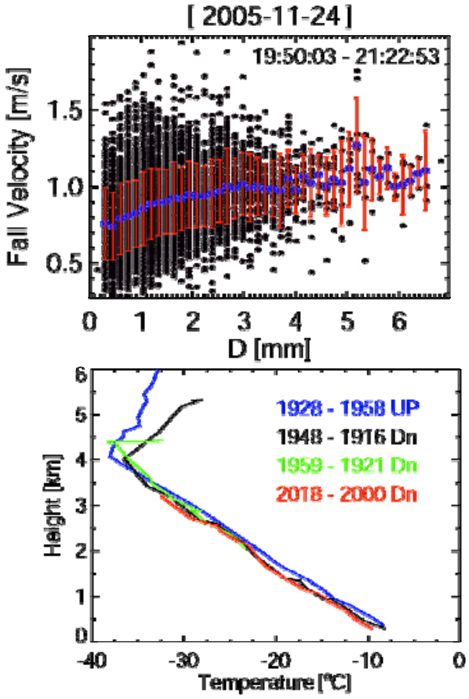

Figure 4: *Scatter diagram of fall velocity and size of snowflakes (upper) on 24th Nov. 2005 at the CARE site. Blue dots and red error bars indicate means and standard deviations of each snowflake particle size interval, respectively. Up (Dn) in Fig. 4 (lower) represent sounding profiles obtained during aircraft ascents (descents), respectively.*

The air temperature at the ground, during the observation, was approximately -9°C, decreasing with height to -38°C at 4km (Fig. 4, lower). In Fig. 4 (upper), the mean fall velocity of snowflake is about 1m/s, but a significant dispersion of fall velocity over the whole range of snowflake diameters can be seen in the *v*-D scatter diagram. This wide spread of fall velocity probably helps to enhance the aggregation process by increasing the chance of collision among snowflakes. The dispersion of fall velocity can be caused by the spread of terminal velocity or affected by the turbulence or resulted from a combination of both effects. Therefore, investigation of homogeneity near the surface can be helpful to verify the existence of turbulence. Standard deviations for horizontal motion and fall velocity are shown in figure 5. To reduce the uncertainty of standard deviations for larger particles owing to the small sampling number, we extended time period which data were analyzed.

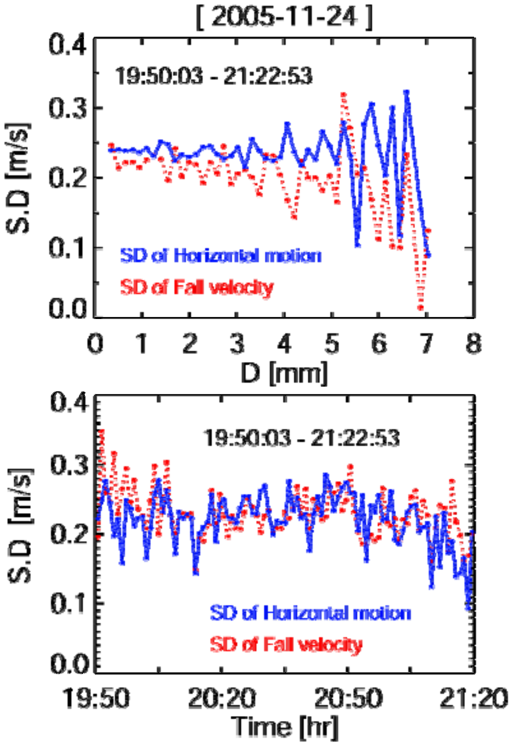

Figure 5: *Standard deviations of horizontal particle motion (blue solid line) and fall velocity (red dotted line) vs. snowflake size (upper) and time (lower), respectively.*

Figure 5 (upper) illustrates standard deviations of horizontal motion (blue solid line) of snowflake particles recorded by the HVSD and fall velocity (red dotted line) with respect to maximum dimension of snowflakes, respectively. We can notice that the standard deviations for horizontal motions are independent of snowflake sizes, remaining constant as snowflakes get larger. In addition, the magnitudes of standard deviations for horizontal motion with the sizes of snowflakes are larger than those of fall velocity as a whole, indicating horizontal variations are larger than vertical variations when they fall. In time series of standard deviations for both horizontal motion and fall velocity (figure 5, lower), the magnitudes of standard deviations are comparable, in general, indicating variations of horizontal motions are as important as motions in vertical. In this situation, comparable magnitude in standard deviations of horizontal motion and fall velocity may increase the chances of collision/collection among snowflakes by increasing the swept volume.

4. SUMMARY AND FUTURE WORK

We have shown results based on the snow case data on 25th Nov. 2005. The temperature at the ground was approximately -9°C, decreasing with height to -38°C at 4 km, illustrating that the lower troposphere was quite cold. Particle images recorded by the HVSD had the appearance of aggregates with holes and rough surfaces, implying significant aggregation can occur with temperatures as low as -9°C. The rate of snow growth calculated by the gradient of reflectivity (dB/km) shows a growth rate, ~10 dB/km, significantly more rapid than that of the commonly observed growth rate, ~4 dB/km. Doppler spectra from VertiX show a large spread as well as reveals zigzag patterns, indicating the existence of strong turbulence. These observations suggest the possibility that turbulence can induce a rapid growth of snow in cold environments. In addition, comparable magnitude of the standard deviations for horizontal motion of snowflakes and fall velocity were observed, suggesting possibility of increasing of swept volume leading to snow growth enhancement by aggregation. However, we need further analyses and more cold snow cases to generalize our conclusion. We will further calculate Doppler velocity spectrum using data from the HVSD and then analyze and compare them with those of VertiX as to validate the accuracy in velocity measurement of snowflakes by the HVSD.

REFERENCES

Barthazy, E., S. Göke, R. Schefold and D. Högl, 2004: An optical array instrument for shape and fall velocity measurements of hydrometeors. *J. Atmos. Ocean. Technol.,* **21**, 1400-1416.

Fabry, F., and I. Zawadzki, 1995: Long-term radar observations of the melting layer of precipitation and their interpretation. *J. Atmos. Sci.,* **52**, 838–851.

Heymsfield, A. J., A. Bansemer, P. R. Field, S. L. Durden, J. L. Stith, J. E. Dye, W. Hall, and C. A. Grainger, 2002: Observations and Parameterizations of Particle Size Distributions in Deep Tropical Cirrus and Stratiform Precipitating Clouds: Results from In Situ Observations in TRMM Field Campaigns. *J. Atmos. Sci.,* **59,** 3457–3491.

Hudak, D., H. Barker, P. Rodriguez, and D. Donovan, 2006: The Canadian CloudSat Validation Project. Proceedings of ERAD 2006.

Zawadzki, I., W. Szyrmer, and A. Bellon, 2007: Phenomenological description of the growth of snow by deposition. *In preparation for submission to J. Atmos. Sci.*