11A.6 OBSERVATIONS OF SNOW GROWTH BY A VERTICALLY POINTING RADAR

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1. INTRODUCTION

Snow growth is initiated by activation of freezing nuclei followed by an initially rapid deposition of water vapour. Subsequent growth involves deposition, riming and aggregation, and under special circumstance secondary ice generation by the Hallet-Mossop process. These processes are controlled by pressure, temperature and humidity and the morphology of snow. Vertical air motions, that have variability at all scales, control the level of supersaturation and the presence of supercooled water. All these processes are extremely variable in time and space so that an example is likely to be found to support whatever hypothesis we care to advance. Thus, the description of average snow growth requires a very large sample of observations if we want to avoid biases due to insufficient sampling. Radar, and in particular vertically pointing radar is perfectly suited for the task. The shortcoming of radar is the limited number of observed parameters. In spite of this limitation radar is a unique tool enabling us to observe the various processes of snow growth and constrain the development of theoretical descriptions of snow growth.

Here we will present a small sample of observations by a vertically pointing X-band radar (VertiX) built and operated by the J.S. Marshall Radar Observatory for a couple of decades.

2. SOME AVERAGE CHARACTERISTICS

One of characteristics of snowfall intensity that strikes an observer is the fact that the reflectivity of precipitation is weakly dependent on the depth of snow growth. An analysis of the growth of reflectivity in the first upper kilometre shown in Fig. 1 provides part of the answer: in shallow systems snow grows extremely rapidly at the top, with rates exceeding 60 dB/km so that 25 dBZ can be attained in the first kilometre of growth.

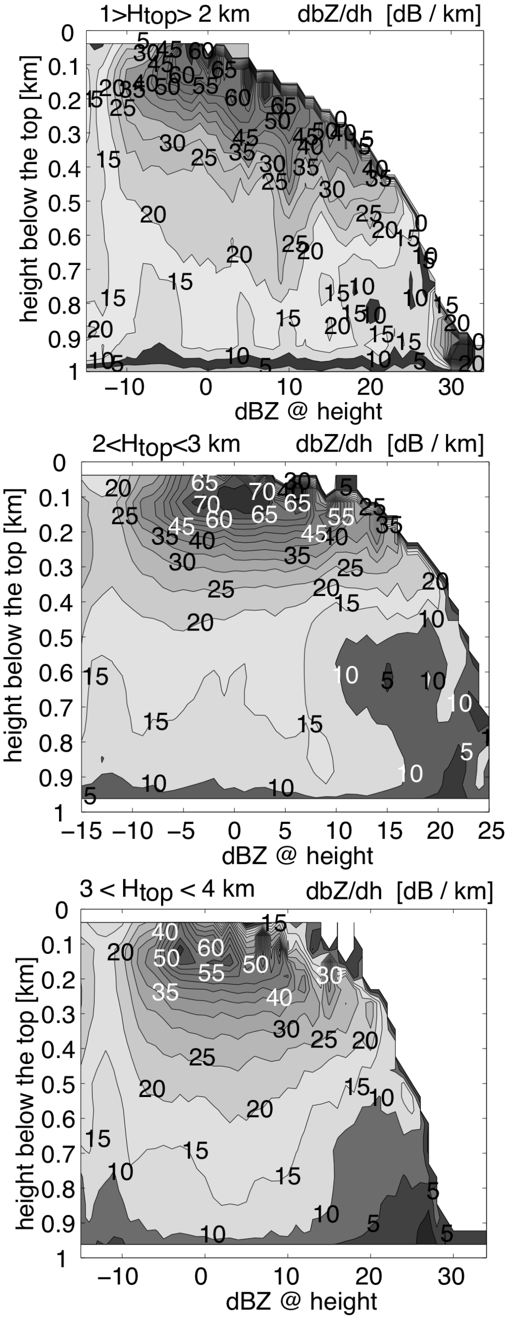

Figure 1- *Reflectivity gradients in snow in the first upper kilometre of detectable growth for echo tops of 1 to 2, 2 to 3 and 3 to 4 km above the 0º isotherm. These diagrams are averages over 34 storms from the period May to November 2005.*

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Deep systems have much lower reflectivity gradients below the first kilometre of growth.

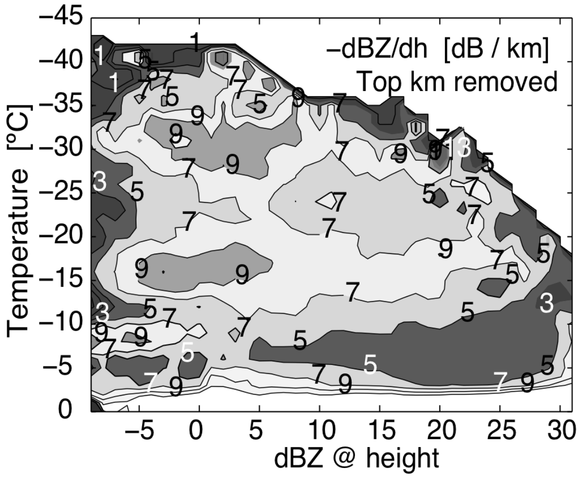

Fig 2- *Vertical gradients of reflectivity in height-temperature-reflectivity coordinates (averages over 34 storms).*

Fig. 2 shows that below the first kilometre of snow growth on the average reflectivity growth is between 5 and 7 dB/km. When height is transformed to temperature (using aircraft soundings when available and interpolation of Albany and Maniwaki soundings otherwise) maxima of reflectivity growth appear at three levels: around -30, -15 and -7ºC. Inspection of individual cases shows that the -30 level is due to insufficient sampling: it is the result of a single event. The lower two minima of reflectivity growth are more pronounced for the lower reflectivity and are associated with the same pattern in Doppler velocity shown in Fig. 3. This figure also shows two levels at which Doppler velocity decrease with fallen height, one in the vicinity of -15ºC and the other close to -7ºC. As for Fig. 2 the decrease in Doppler velocity is less pronounced as reflectivity increases. As has been described by Zawadzki et al (2001), the -7ºC minimum can be explained by secondary ice generation (at the higher reflectivity) and/or generation of supercooled droplets (lower reflectivity) associated with vertical air motions above the melting layer. The creation of the slower falling particles shifts the Doppler velocity to lower values. Moreover, upward air motions must be present at -7ºC for this systematic creation of new particles. These updrafts add to the decrease in Doppler velocity.

Inspection of individual cases shows that both minima are a common occurrence

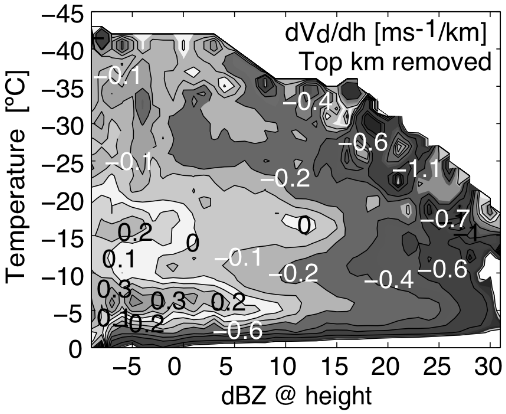

Fig. 3-*Vertical gradients of Doppler velocity in temperature-reflectivity coordinates.*

On the other hand, the decrease in the vicinity of -15ºC is very intriguing because this is the level where dendritic growth is expected to be dominant. But this is an unlikely explanation for the observed drop in Doppler velocity since snow particles do not suddenly mutate into dendrites when they pass through the dendritic growth region. Although some change in fall speed may happen it must be minimal, at least on the average. A look at a particular case will illustrate that the explanation must be looked for elsewhere.

3. SECOND LEVEL OF SNOW GENERATION

On the right of the upper panel Fig. 4 shows a one hour of time-height (or time-temperature) profile of Doppler velocity above the bright band. The minimum at ~ -15ºC is persistent over the entire period and and it is clearly seen on the average velocity profile on the left. Note the high degree of turbulence and some upward motions around 21:00. The sample of Doppler spectra below show the bi-modality starting at near -7ºC produced by the creation of new particles as mentioned before. This illustrates the origin of the lowest decrease of Doppler velocity.

At 5 km above ground, where the -15 ºC is found, the spectra show a sudden and strong increase in intensity. At the same time the entire spectrum shifts to lower velocity. These features are quite common in the sample of cases studied.

Appearance of new dendrite particles would broaden the spectra toward lower velocity. For this, a mechanism of activation is needed and it can only be provided by upward air motion. The solid decrease in velocity would require all particles to be equally slowed down by dendritic growth. An alternative explanation is upward air motion. The lower row of Fig.4 sheds light on the nature of this storm: it is the superposition of a low level system with tops near the -15ºC and snow falling from a much deeper, but less intense, system. The upward air motion at the top of the lower system is close to w=1 m/s (0.85 m/s is indicated at ~ 19:00 where the reflectivity is -15dBZ). This w represents a second level of snow generation for the deep storm and it is at the origin of the -15ºC drop in Doppler velocity.

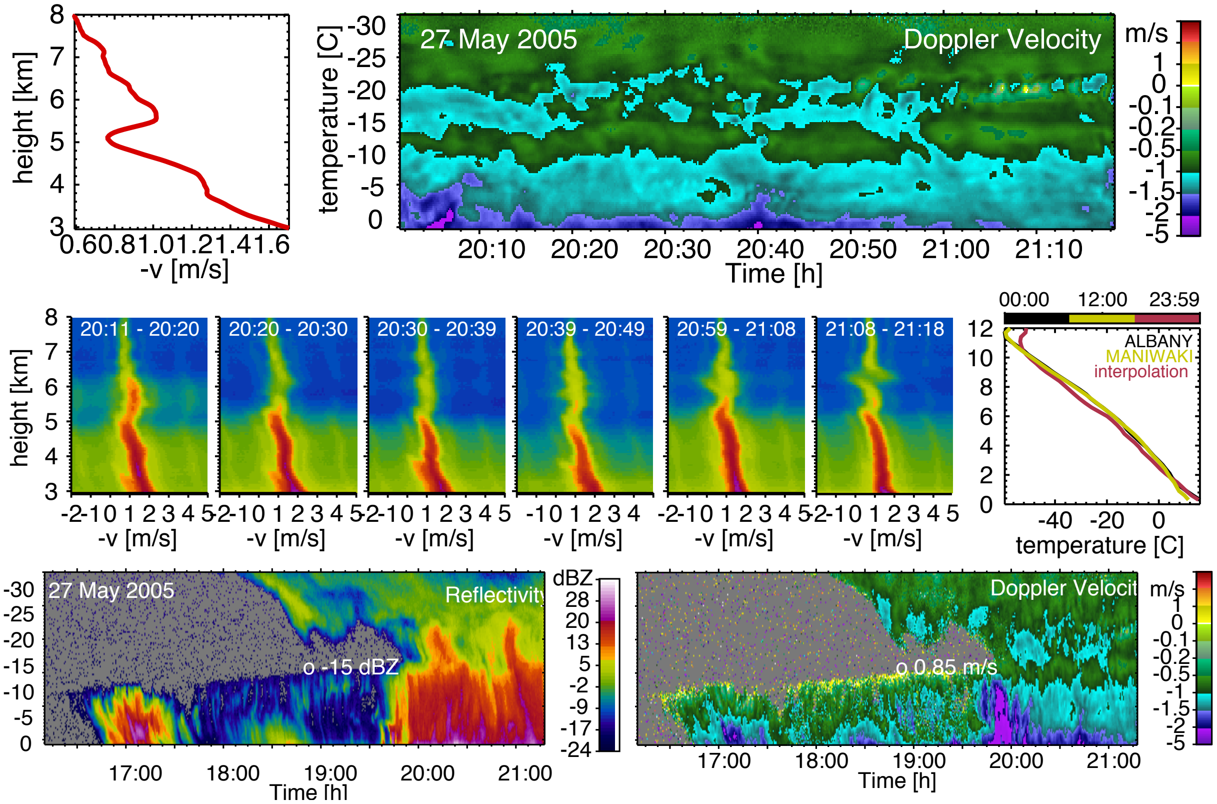

Fig. 4. *Upper row, Left: the average profile of Doppler velocity; Right: Temperature-time profiles of Doppler velocity. Middle row (left): selected Doppler spectra; Right: temperature soundings. Lower row: Temperature-time profiles of reflectivity and Doppler velocity for a longer period.*

4. ROLE IN PARTICLE CONCENTRATION

The change in the reflectivity gradient in Fig. 5 suggest that in this case three levels of generation could be present: the first above the level of -30C, a second at around -22C and the third level of snow generation at around -15C, as. The middle row with the Doppler profile shows a persistent minimum peaking at around -15 C. Most revealing is the sequence of Doppler spectra in the lower row where appearance of bi-modality is clearly associated with upward air motion. Particles falling from upper levels (peak on right) are solidly displaced toward lower velocities consistently with the occurrence of updraft. Secondary peaks (on left of spectra) are distinctive indication of activation of new, small and slow-falling, particles. Some of these could be dendrites but supercooled droplets are likely to be present as well, particularly in those periods where the secondary peak runs parallel to the main one for 2 km. At other times the slower particles rapidly grow to join the main peak.

The presence of the second level of snow generation could explain the anomalously large number of small particles often observed in aircraft samples and its explanation requires a mechanism of particle activation activation.

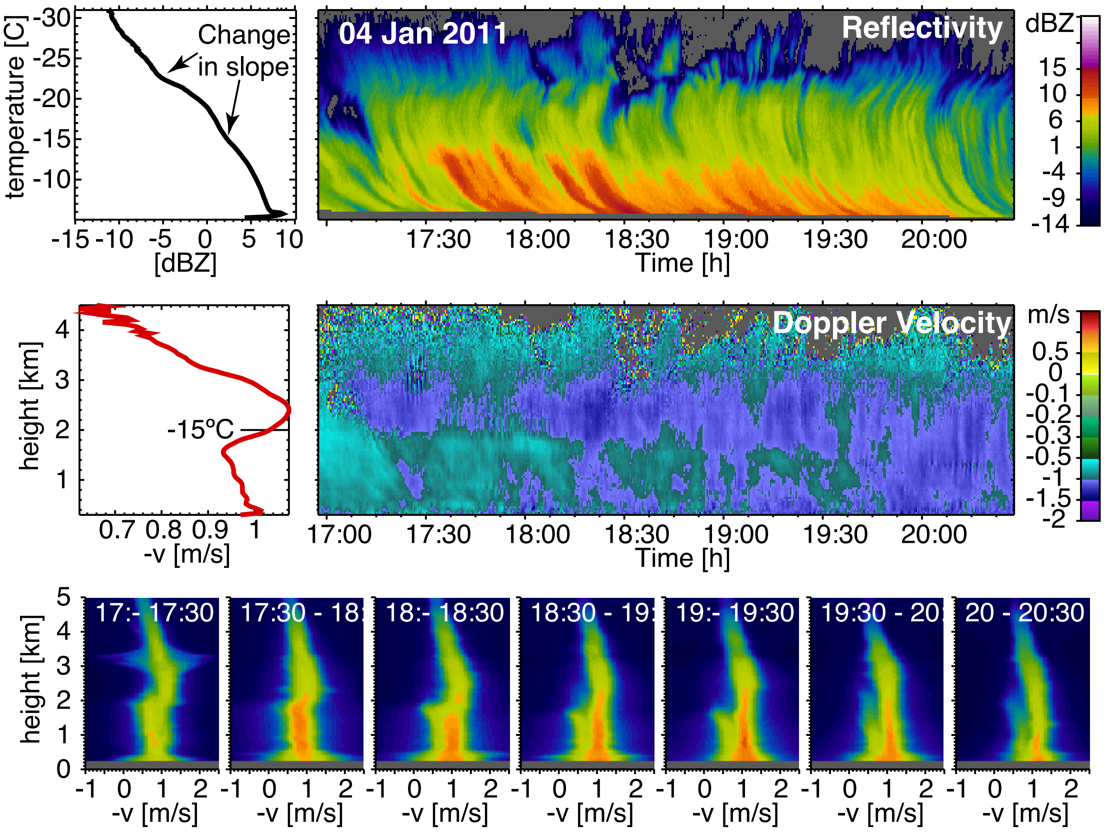

Fig. 5- Top row: reflectivity profile and ita time sequence; middle row: same for Doppler velocity; bottom row: a sample of time averaged Doppler spectra.

4. DISCUSSION

The average gradients of reflectivity and Doppler velocity in snow for 34 cases of stratiform precipitation (defined by the presence of a well defined bright band) shows that in shallow systems the first kilometre is critical for the growth of snow to its final intensity. The extremely rapid growth partially compensates for the lack of depth in precipitation growth. The remaining growth ranges from 7 to 5 dB/km. However, there are two levels that exhibit faster growth and it is associated with temperatures of close to -15C and to -7C. The gradients of Doppler velocity have a pronounced drop at the same levels. We have seen that the first is associated with vertical air motion. Simply, the most frequent level of non-divergence is in the vicinity of -15ºC. For systems with precipitation extending toward colder temperatures this leads to a second level of generation of precipitation. If the associated updraft generates sufficient humidity, new nuclei (freezing or condensation) can be activated and the number concentration of small particles may increase. If these particles attain detectable size bi-modality in Doppler spectra is observed.

Generation of new particles at -7ºC, as revealed by the appearance of bi-modality in the spectra, is associated with the lowest drop in gradient of Doppler velocity. It is not clear from the observations whether there is a general updraft at this level (the high level of turbulence makes it difficult to discern) but it must exist for the generation of new particles to happen.

Air motions in stratiform precipitation can be present at all scales and new nuclei could be activated whenever the updrafts are sufficiently strong to produce humidity at a rate faster the rate of deposition on the existing snow.

Reference

Zawadzki, I., F. Fabry and W. Szyrmer, **2001**: Observations of supercooled water and of secondary ice generation by a vertically pointing X-band Doppler radar. Atmospheric Research, **59-60**, 343-359.