Vertical Structure and Dynamical Properties during Snow Events in Middle Latitudes of China from VPR-CFMCW Observations

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The continuous observation data of 4 shallow snow events and 2 deep events was obtained by the C-band vertically pointing radar with frequency modulation continuous wave technology (VPR-CFMCW) during the winter of 2015–2016 in middle latitudes of China, which was helpful to understand the vertical fine structure and dynamical properties inside the snow clouds. Generating cells (GCs) described in previous research had been found near the cloud tops in every event. The vertical air velocity (W_a) and reflectivity-weighted particle fall speed (V_z) retrieved from bimodal spectra were used to analyze the dynamical properties in the snow clouds. The main conclusions of this study may be summarized as follows:

1) According to the characteristics of echo distribution and the changes of velocity gradient and spectral width, snow clouds could be divided into upper GC regions and lower stratiform (St) regions. For the shallow events, statistical analyses of the GC regions indicated that they typically have a depth of 500–1200 m. The depths of GC regions accounted for about 10–13% of the whole cloud, while the average contributions to the growth of reflectivity (Z) values reached 42% in these regions. GCs occurred up to 23 times within 1 h, resulting in dense fibrous fall streaks (FSs) below. As for the deep events, the depths of GC regions were greater, reaching over 2 km. The times of GC occurrence within 1 h were about one third to one half of those in the shallow events, leading to the relatively sparse FSs and uniform St regions below. The depths of GC regions accounted for about 16% of the whole cloud, while the average contributions to the growth of Z values reached 33% in these regions. The contributions of GC regions to Z value growth were larger than those to ice mass growth described in some previous studies. In the deep events, the proportions of GC regions were slightly larger, but the average contributions to the growth of Z values were lower than those in the shallow events. The depths of GC regions are in good accord with previous studies.

2) The relative humidity with respect to ice (RH_i) values in the GC regions were all greater than 120% for the 6 events. In the deep events, the ice particles in the GC regions may feature high number concentration and slow growth rate, while Z is more sensitive to the changes in particle size. This was most likely the reason for the slower increase in Z values within the GC regions during the deep events. During the shallow events, due to the higher temperatures in the GC regions, supercooled water may still exist. Thus the ice particles may grow through deposition and riming.

3) Between the 2 types of events, the differences of average gradients of Z ($\tilde{N}Z$) in GC regions were significant, while the differences in St regions were relatively small. In the shallow events, the differences of average $\tilde{N}Z$ between the 2 regions were greater than those in the deep events. The 2 types of events also had similarities: the average $\tilde{N}Z$ values were usually 2–3 times (average 2.4) larger inside GCs compared to outside, and the differences between the inside and outside of the FSs were of similar magnitude. To some extent, the result indicated the importance of GCs to the enhanced ice growth subsequently observed in FSs.

4) The upward and downward motions coexisted in the GC regions. The distribution range of W_a was

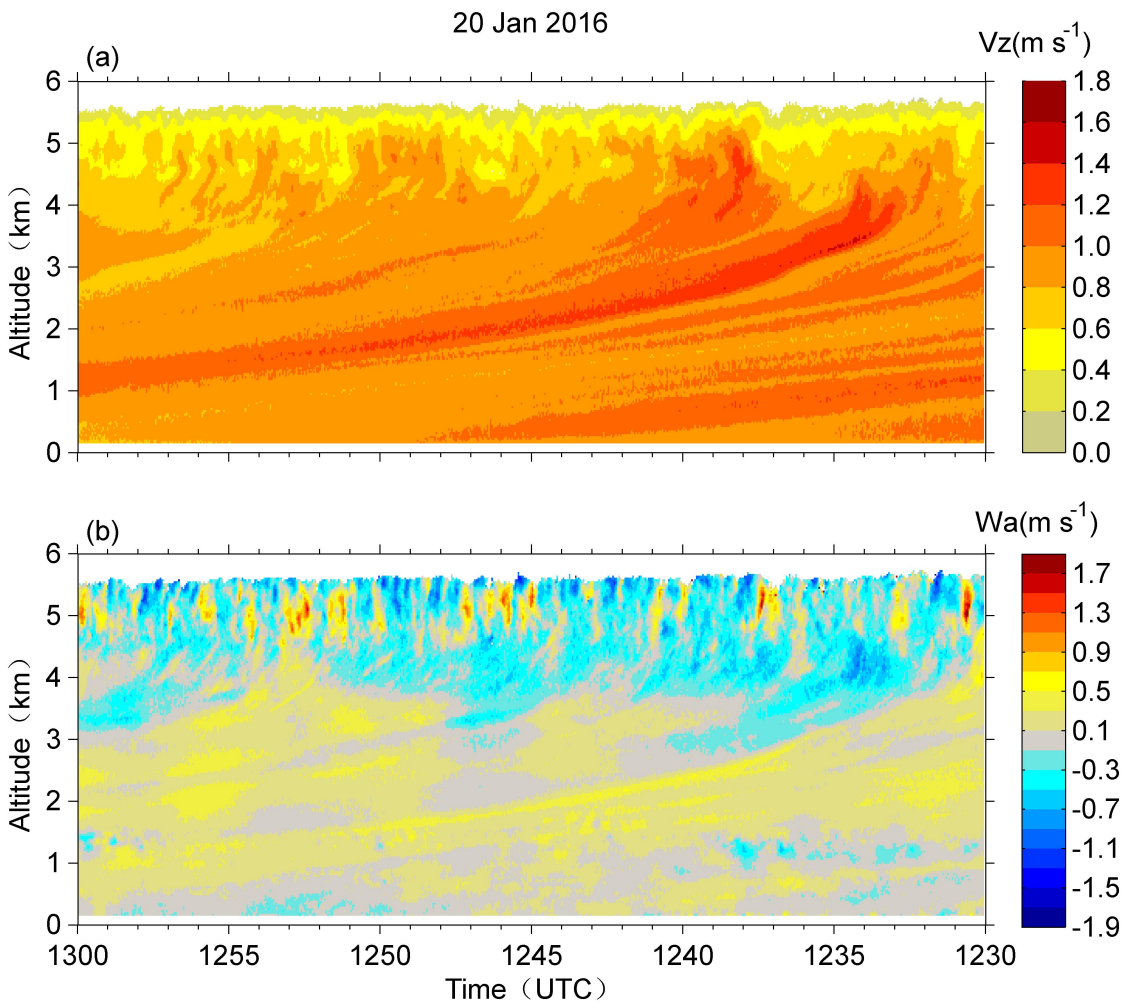
mainly between −1.7 and 1.2 m s^{-1} for the 2 types of events, which was similar to previous studies. GC locations usually correlated with strong upward air motions, while downward air motions often appeared in the regions between GCs. The upward air velocities within GCs for the 2 types of events were similar, and the average speeds were mostly distributed around 1.3 m s^{-1}. The downward air motions between GCs were weaker in the deep events.

In the St regions, the speeds of W_a were mainly within 0.5 m s^{-1}. There were no apparent dynamical features within the FSs. The upper areas of the St regions consisted primarily of weak upward motions, which was in good accord with previous studies, while weak downward motions dominated the lower areas. The depths of updraft areas accounted for smaller proportion of the St regions during the shallow events compared to the deep events.

5) In the GC regions, the increments of V_z during the shallow events were greater than those during the deep events. The average speeds were slightly faster inside GCs and FSs compared to outside, with the differences between 0.1 and 0.3 m s^{-1}. The differences of V_z between the inside and outside of GCs were slightly larger during the shallow events compared to the deep events. The enhanced V_z within GCs and FSs implied the more conducive conditions for particle growth existed in GCs and FSs.

The results of this study have clarified findings of the past half-century. The W_a and V_z values were retrieved more precisely using bimodal spectra from VPR-CFMCW. The continuous evolution and statistical characteristics of W_a and V_z in the entire snow clouds were also obtained, providing a more comprehensive understanding of the GC and St regions. Moreover, characteristics of GC regions, as well as the average reflectivity gradients and dynamical properties inside and outside GCs and FSs, were quantified. The results in this research may improve the understanding of the differences between the inside and outside of GCs and FSs during the 2 types of snow events in terms of vertical reflectivity gradients and dynamical properties.

Keywords: VPR-CFMCW, Generating cell, Doppler spectra, Vertical air motion, Reflectivity-weighted particle fall speed, Snow event


20 Jan 2016
(a)
Vz(m s-1)
Altitude（km）
0
1
2
3
4
5
6
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b)
Wa(m s-1)
Altitude（km）
1.7
1.3
0.9
0.5
0.1
-0.3
-0.7
-1.1
-1.5
-1.9
1300
1255
1250
1245
1240
1235
1230
Time（UTC）