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SNOW CLOUDS OBSERVATION USING THE AIRBORNE CLOUD RADAR (SPIDER)

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1. INTRODUCTION

Identification of cloud water phase, such as liquid water or ice water is important for the Earth radiation budget (Brown et al. 1995). Multiparameter radar data, such as LDR (Linear Depolarization Ratio) and $\rho_{HV}(0)$ (correlation between both horizontal and vertical polarization with zero time lag) are useful. Meanwhile satelliteborne cloud profiling radar (CloudSAT) can measure Z factor only, and other radar (EarthCARE/CPR) can measure Doppler Velocity in addition to Z factor. Under this situation, algorithm development to identify cloud water phase is preferred.

The National Institute of Information and Communications Technology (NICT) has been conducted various airborne experiments using the 95GHz cloud radar (named SPIDER) (Horie et al. 2000). SPIDER is dual polarized radar using linear polarization and has dual receivers for both polarizations. The pulse-pair processing capability is also provided. Therefore, multi-parameter data, such as Doppler velocity, LDR, $\rho_{HV}(0)$, in addition to Z factor can be obtained. The sea surface return data were also obtained because the difference between expected and received surface returns was caused by attenuation of the atmosphere and cloud liquid (or snow/rain). The sea surface is considered useful calibration target for spaceborne cloud radar (Horie 2004) and has stable scattering property as the others results by lower frequency (Masuko et al. 1986, Jackson et al. 1992, Okamoto et al. 2002, Freilich and Vanhoff 2003).

The observations of snow clouds were performed as part of Winter MCSs (Mesoscale Convective Systems) Observation over the Japan Sea in 2001, 2002 and 2003 (named WMO-01, WMO-02 and WMO-03). SPIDER was carried by Gulfstream II airplane, which was also mounted Microwave Radiometer (WVR-1100) and "in-situ" cloud particle measurement sensor (FSSP, 2DC, and 2DP probe) operated by Meteorological Research Institute, Japan. During observation, the developmental stages of snow clouds were observed.

At the initial stage of developing snow, updraft at the lower altitude is found and little attenuation is occurred. At the mature stage, both strong updraft and down draft at middle altitude are found and strong attenuation is occurred. At decaying stage, only down drafts at the low and middle altitude are found and little attenuation is occurred. It is considered that the attenuation is caused by not cloud ice water but cloud liquid water. The temperature at the cloud bottom was below zero degrees, then cloud particles contained super-cooled droplet in clouds.

The cloud water detection using received power only is applied to the data during airborne experiments by SPIDER. The comparison with the result of Doppler velocity is also applied. The detected cloud water is agreed with the result of Doppler measurement.

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2. RADAR PARAMETER

SPIDER is W-band (95GHz) multiparameter radar and the parameter of Z factor, Doppler velocity, LDR and $\rho_{HV}(0)$ can be used for airborne observation of nadir looking. Over the ocean, sea surface return can be used to estimate attenuation by cloud water . In the case of near nadir incidence, the sea surface return or NRCS (normalized sea surface radar cross section) of lower frequency than W-band frequency can be calculated from the quasi-optical scattering model with parameter of wind speed (Valenzuela 1978). The NRCS of W-band frequency was measured in which various wind speed (Horie 2004). The radio wave is attenuated by scattering and absorption, but attenuation by scattering is neglect in this paper. So one-way attenuation of radio wave (Att) [dB] is expressed as,

$$Att = \int_0^r k dr \quad (1)$$

where k is specific attenuation [dB/km] and r is range [km] from radar. Attenuation is caused by atmosphere and cloud, then k is expressed as,

$$k = k_{wv} + k_{cl} \quad (2)$$

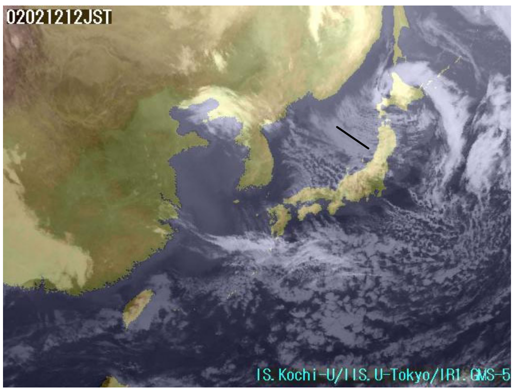

Figure 1 Flight Path

where k_{wv} is specific attenuation by water vapor and oxygen, and k_{cl} is specific attenuation by cloud. k_{wv} can be calculated using meteorological data. k_{cl} can be expressed using ρ: the density of hydrometeor and M: mass of hydrometeor, in the case of Rayleigh scattering,

$$k_{cl} = 8.19\,\mathrm{Im}(-K)M/\lambda\rho \qquad (3)$$

which shows that k_{cl} is a function of the temperature and phase state of the hydrometeor through the term Im(-K). K is refractive indices. Im(-K) of cloud ice and water are 1.436e-5, 1.876e-1 for 94GHz at 0C, and the specific attenuations are 1.8e-4 and 4.82, respectively (Meneghini and Kozu 1990). The attenuation of cloud ice is negligible, but that of cloud water is not negligible. The difference between expected value and measured value is caused by cloud water. M of equation (3) is rewritten using LWC: liquid water content at the range,

$$M(=LWP) = \int_0^r LWC(r)dr \qquad (4)$$

where LWP is liquid water path. LWP is measured by microwave radiometer. The LWP of cloud can be measured from the depression of NRCS.

3 CLOUD OBSERVATION

The airborne experiments were done over Japan Sea area at the winter season in 2001 to 2003. Airplane carried "in-situ" measurement sensor, drop sonde system and microwave radiometer in addition to SPIDER. The major flight pattern was that across over the snow cloud about 5 to 8 km altitude with radar observation, radiometer observation and drop sonde measurement, then "in-situ" measurement was done low altitude between cloud top and cloud bottom.

The result of snow cloud observation is picked up to demonstrate multiparameter radar

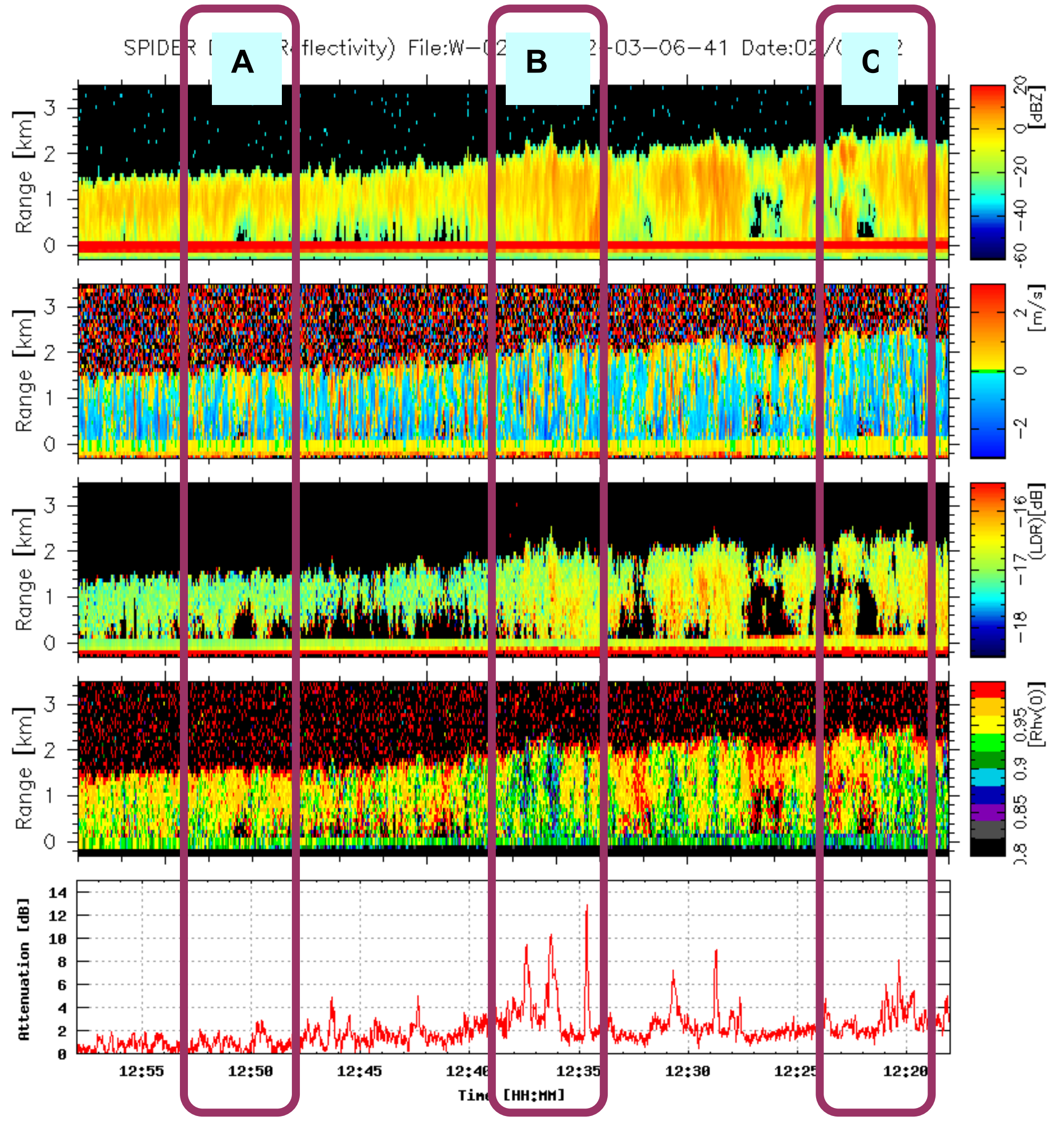

Figure 2 Multiparameter data of snow cloud observation along flight path
1) Top Panel; Z factor, 2) Second Panel; Doppler velocity (downward: minus or blue color), 3) Third Panel; LDR, 4) Fourth Panel; $\rho_{HV}(0)$, 5) Bottom Panel; Attenuation
Mark "A": initial stage, "B": developing stage, "C": mature stage.

observation. Observation was done part of WMO-02 at Japan Sea. The flight path is shown in Figure 1. The development of snow cloud is observed. Each radar parameters and attenuation over the pass are shown in Figure 2. $\rho_{HV}(0)$ is related to shape of cloud particle. When particle is sphere, value is one, and value becomes lower when particle is far from sphere. LDR is also related to cloud particle shape, but relation is opposite to $\rho_{HV}(0)$. When particle is sphere, value is low, less than -30dB. When particle is far from sphere, LDR becomes larger. The echo height of right side (near land) is higher than that of left side (off land). The left side part (marked "A") is shown initial developing stage of snow cloud, the middle part (marked "B") is shown mature stage, and right side part (marked "C") is shown decaying stage.

Figure 3 shows the comparison between LWP measured by microwave radiometer and LWP calculated by attenuation of NRCS using radar reflectivity. The absolute value is slightly

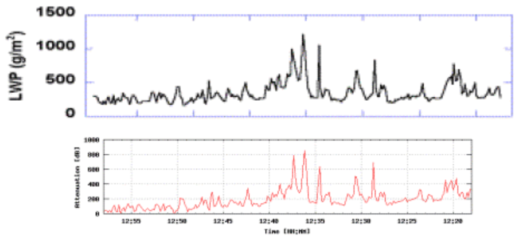

Figure 3 Liquid Water Path
A) Top Panel: LWP measured by microwave radiometer
B) Bottom Panel: LWP calculated by the depression of NRCS

different because of averaging period, but the main feature is consistent. It indicates that the main reason of attenuation caused by absorption of cloud water and the attenuation by the scattering of large particle is negligible. After this, LWP is shown in figures instead of attenuation or depression of NRCS.

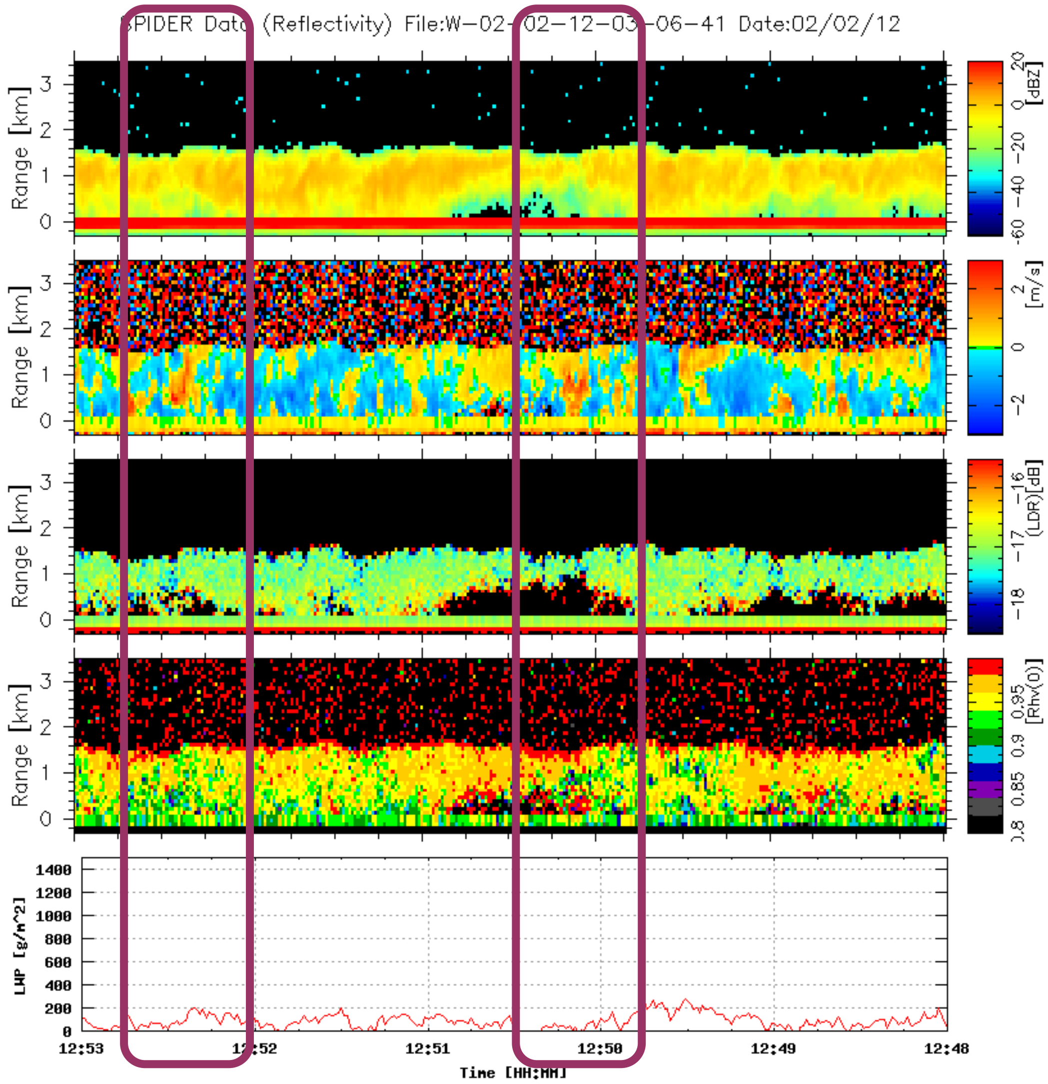

Figure 4 Multiparameter data of snow cloud observation in initial stage (Figure 2 - "A")
A) Top Panel; Z factor, B) Second Panel; Doppler velocity (downward: minus or blue color), C) Third Panel; LDR, D) Fourth Panel; $\rho_{HV}(0)$, E) Bottom Panel; Liquid Water Path.

In the initial stage (showed in Figure 4), up draft at the middle of cloud is existed in Vd panel, it indicates the existence of super cooled water. The amount of water is not much because the depression of NRCS is not recognized. The diameter of water particles may be too small to attenuate.

Figure 5 shows close up image of the developing stage. In the middle, high attenuation is recognized. At the same time, high LDR and worse $\rho_{HV}(0)$ are shown. The Doppler velocity is strange. The strong upward velocity in the middle and strong downward velocity at the both side are shown. It indicates the existence of large amount of water and the large particle such as graupel maybe existed.

At the mature stage (showed in Figure 6), high Z value and strong lower Doppler velocity were observed, but no significant attenuation was existed. It might be heavy snowfall at that area.

SUMMARY

From the result of the experiments, it is shown that multiparameter radar data, such as Doppler velocity, $\rho_{HV}(0)$ and LDR, in addition to Z factor are useful to identify water phase. Meanwhile satelliteborne cloud profiling radar (CloudSAT and EarthCARE) has a capable to measure Z factor (and Doppler velocity for EarthCARE), only. LWP calculated from the depression of NRCS, is also shown, and the method will be used by satelliteborne cloud radar.

Each feature of the snow cloud system was obtained. The multiparameter data is helpful to study microphysics of developing snow in clouds.

The comparison of "in-situ" particle data will be necessary, it must be done later.

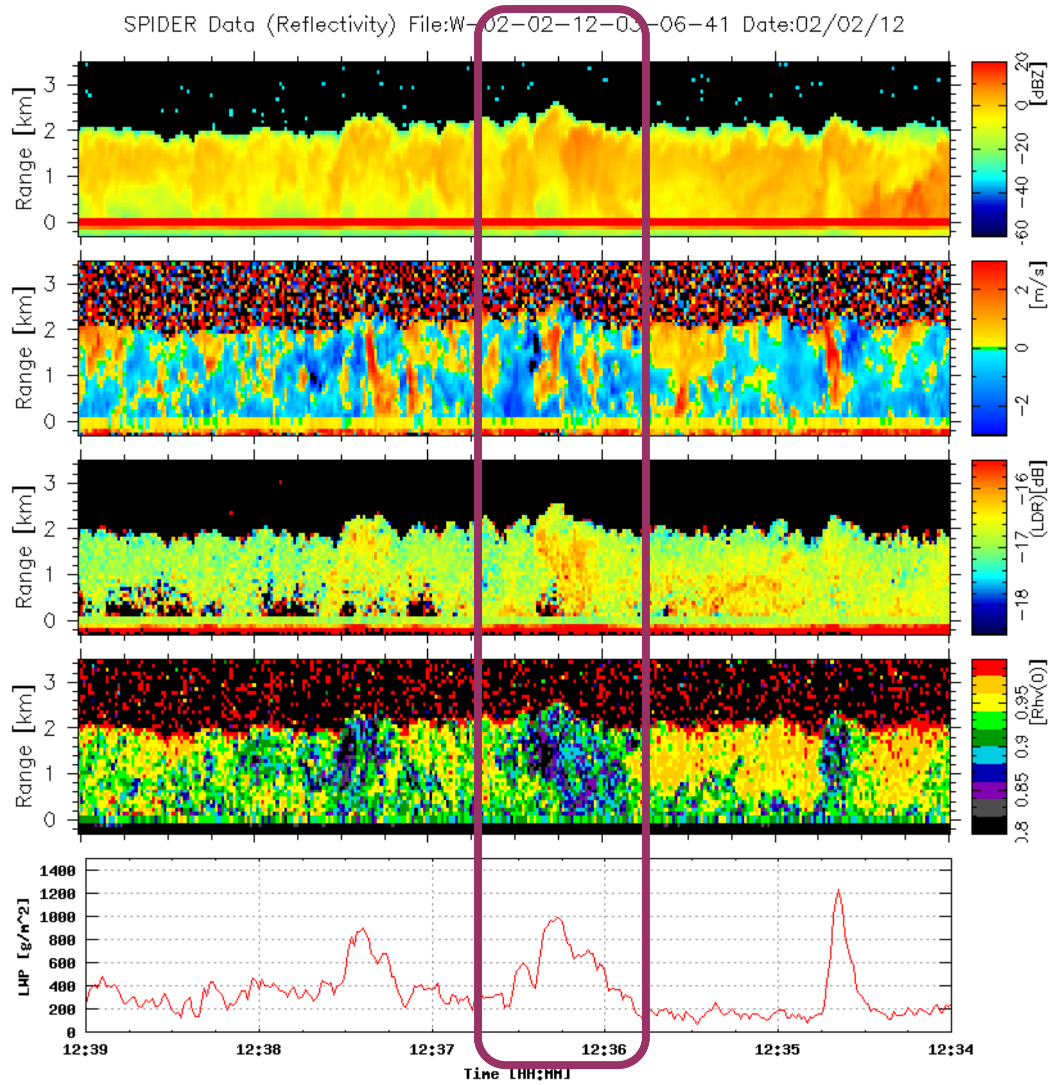

Figure 5 Multiparameter data of snow cloud observation in developing stage (Figure 2- "B")
A) Top Panel; Z factor, B) Second Panel; Doppler velocity (downward: minus or blue color), C) Third Panel; LDR, D) Fourth Panel; $\rho_{HV}(0)$, E) Bottom Panel; Liquid Water Path.

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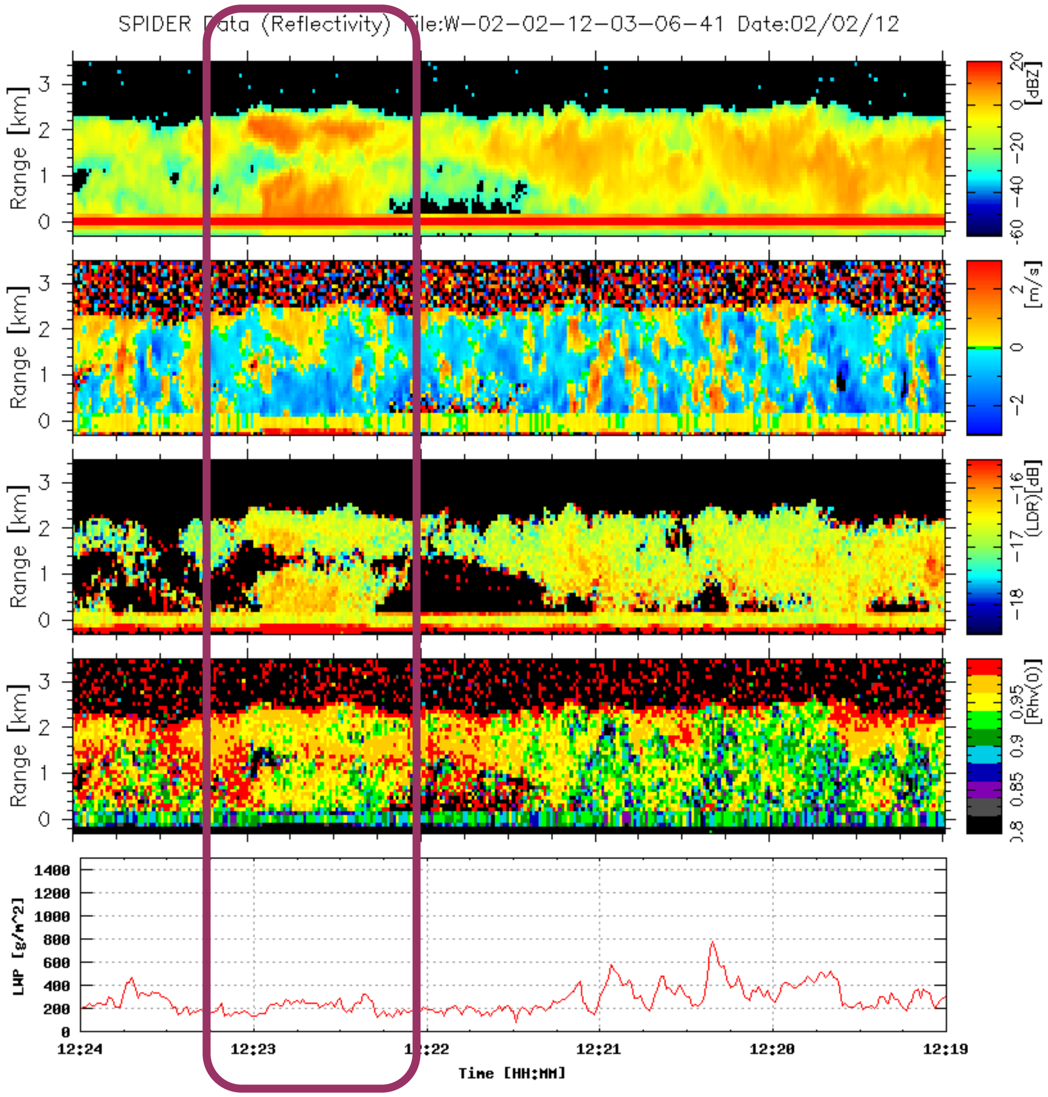

Figure 6 Multiparameter data of snow cloud observation in mature stage (Figure 2- "C")
A) Top Panel; Z factor, B) Second Panel; Doppler velocity (downward: minus or blue color), C) Third Panel; LDR, D) Fourth Panel; $\rho_{HV}(0)$, E) Bottom Panel; Liquid Water Path.