Characteristics and Evolution of Clear Air Echoes Observed by Okinawa Polarimetric Doppler Radar (COBRA)

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1. Introduction

Clear air echoes (CAEs) observed by weather radar have been recognized since the 1940s (Atlas, 1990). The scattering objects include not only birds and insects but also atmospheric turbulence. The CAE formed by turbulence is observed particularly over land warmed by solar radiation. Although a weather radar usually measures precipitation particles through the Rayleigh scattering, it also measures variations of atmospheric refractivity caused by turbulence through the Bragg scattering as a wind profiler. A C-band (5 GHz) weather radar is at a disadvantage to measure turbulence due to the shorter wavelength (Ralph, 1995), while some results about the CAE observation have been reported (Kusunoki, 2002; Takahashi, et al., 2004, 2005).

Convection in atmosphere is called by some names, which are plume, thermal, cumulus and cumulonimbus, according to their scales. Plume is a small-scale thermal with a root which is a fixed heat source. Although plume and thermal are usually invisible, cumulus and cumulonimbus are visible by clouds. Cumulus convection is generated in the environment of convective instability. When an air mass with water vapor is lifted up to a condensation level, cloud droplets are generated by condensation. There are some reasons of the first opportunity of lifting up the moisture air mass. Wind convergence at surface, which is caused by the discontinuity of temperature, roughness, topography, and so on, is one of the reasons. In addition, the fluctuation of the surface temperature caused by solar radiation should be another reason. In most cases, the first convection is occurred in the atmospheric boundary layer (ABL). In the ABL with alive turbulence, many thermal convections generated by the solar heating. The thermal may be one of the causes of an outbreak of cumulus convection over the warmed land surface. However, the relation between the thermal and the cumulus convection has not been cleared.

In this study, the C-band Okinawa Bistatic polarimetric Radar (COBRA) developed by NICT (Nakagawa, et al., 2003) is used to investigate the characteristics of CAE and its evolution into cumulus convection. The advanced C-band radar, which measures polarimetric parameters and Doppler velocity, is expected to reveal the convective evolution from thermal to cumulus.

2. Observation and Data

From June 29 to July 10, 2005, a campaign experiment was conducted by NICT Okinawa and HyARC Nagoya university members as one of Lower Atmosphere and Precipitation Study (LAPS) projects. In addition to the COBRA observation, GPS radiosonde sounding every two or three hours, optical video observation, and 400 MHz wind profiler (WPR) observation were carried out. The contents in detail of the IOP experiment is reported by Furuzawa (2005). The COBRA observation sequence every 10 minutes includes three PPI scans at 1.4, 7.0, and 8.0 degrees in elevation angle, and continuous fourteen RHI scans every 30 seconds at 41.2 degrees in azimuth angle. The azimuth angle is a direction from the COBRA to the WPR site. The COBRA observation range is 20 km, the range resolution is 75 m with 0.5 µs pulse width, and the elevation angle resolution is about 0.4 degrees (the antenna beam width is
0.9 degrees). The polarization observation is conducted by alternate H and V transmitting pulse by pulse and simultaneous H and V receiving to measure differential reflectivity (ZDR), linear depolarization ratio (LDR), and so on. Doppler velocity and phase information, such as differential phase shift (φDP), cross correlation coefficient (ρHV), are also recorded.

3. Extraction of CAE

The COBRA data near the land surface during the clear air observation is contaminated by ground clutter echoes. Although the side-lobe level of the COBRA antenna is less than –28 dB in the elevation direction, the RHI scan drags the intense ground echoes over 60 dBZ into the upper clear regions. Figure 1 shows an example of the observation data. Although most of the echoes appeared in horizontal reflectivity (ZHH) are ground clutter, the valid Doppler velocity region less than about –2.5 m/s looks like concrete CAEs. Since the ground clutter echoes do not move, it is possible to extract the clutter echoes by subtracting around zero Doppler. In this study, the condition of both –0.5 < V < +0.5 m/s and NCP < 0.2 is used to extract the ground clutter echoes. Where, V is Doppler velocity, and NCP is Normalized Coherent Power. The NCP condition is used to subtract the noise-level data, because the NCP is effective to distinguish the valid velocity data from noise-contaminated data. According to the simple procedure, the CAE distribution is revealed as shown in Fig. 1 (b). The inversed U-shape echo indicates a vertical slice of the hanging bell-shaped echo by thermal (Hardy and Ottersten, 1969; Konrad and Robinson, 1970). Note the reflectivity values in the ranges less than 2.5 km are weakened, which may be caused by a hard-ware problem.

![Fig.1 Vertical sections (RHI) of (a) observed reflectivity (ZHH), (b) extracted CAEs, (c) observed Doppler velocity (d) observed NCP.](image)

4. Characteristics of CAE

Figure 2 shows three kinds of CAEs represented by ZHH, ZDR, and ρHV. Although a typical CAE, which has the maximum altitude less than 2 km, has been shown in Fig. 1 (b), here, other significant CAEs are shown in Fig. 2. The developed CAE shown in Fig. 2 (a) achieves the altitude of more than 2 km, and the horizontal scale is between 1 km and 1.5 km. The ZDR value around zero in Fig. 2 (b) means the difference between horizontal and vertical size of the targets is small. The higher ρHV around 0.9 in Fig. 2 (c) appeared at the upper regions of the CAEs. Although the ρHV represents the shape and the rotation of the targets, it is difficult to explain the distribution of ρHV in the CAEs because the turbulence structure in the inertial region seems to be isotropic. The larger CAE shown in Fig.2 (d) achieves the altitude of more than 2.5 km, and the horizontal scale is between 2 km and 3 km. Since the turbulence scale increases with altitude, the observation result is consistent with the theory. Two or
three tower echoes like plume expand to 3 km in altitude. While the ZDR in Fig. 2 (e) values are around zero, the ρHV values in Fig. 2 (f) within the plume-like echoes are almost one, which is the same value for small precipitation particles. Figure 2 (g), (h), (i) show the quite different distributions of ZHH, ZDR, and ρHV at the horizontal distance between 4 km and 9 km comparing with the above mentioned CAEs. The shape and characteristics of the echo are different from the turbulence echoes, though the echo is also observed in clear air. The strong reflectivity over 18 dBZ, the higher ZDR, and the lower ρHV may indicate the biological echoes, such as birds and insects. This group echo moves to downwind direction at the wind speed. The similar echoes were observed two or three times during the IOP 2005.

5. Cumulus evolved from CAE

Figure 3 shows the time change of a significant plume-like tower echo, which develops rapidly up to an altitude of 3.5 km at 0513Z. The reflectivity over 10 dBZ appeared around a distance of 8 km at 0513Z, 0514Z, and 0515Z is larger than the usual turbulent echoes. The horizontal size of the tower echo is about 500 m. Since the mean wind direction is a little different from the RHI slice direction, the horizontal cross section is shown in Fig. 4. Figure 4 (a) reveals a doughnut-shaped echo around x=3 km and y=4.5 km, which indicates a horizontal slice of the hanging bell-shaped CAE. The relatively lower ρHV in the doughnut-shaped echo in Fig. 4 (c) seems to represent the horizontal slice of the lower altitude of the bell-shaped CAE. Although the inversed U-shaped echo is not clear in the vertical cross section in 45 seconds in Fig. 4 (d), the horizontal slice line along the PPI at the elevation angle of 8.0 degrees indicated by a solid line in Fig. 4 (d) locates below the developing CAE at the distance between 5 km and 8 km. Figure 4 (d) also shows the higher ρHV region appears in the tower echo. The center of the doughnut-shaped echo at 0511Z in Fig. 4 (a) will moves onto the distance of about 7 km at 0513Z in Fig. 3 (d) according to the mean wind speed and direction (referred by an arrow in Fig. 4 (a)) observed by the 400 MHz WPR. This result indicates that the rapid development of the tower echo shown in Fig. 3 (c) and (d) appears above the doughnut-shaped CAE.
Fig. 3  Time change of reflectivity (ZHH) in the vertical section (RHI) at 41.2 degrees in azimuth at (a) 0505Z, (b) 0508Z, (c) 0511Z, (d) 0513Z, (e) 0514Z, and (f) 0515Z, 07 July 2005.

Fig. 4  Reflectivity (ZHH) on the (a) PPI at 8.0 degrees in elevation and (b) RHI at 41.2 degrees in azimuth at 051059Z, and 051143Z, respectively. (c) and (d) are the same as (a) and (b) except cross correlation coefficient (ρHV).
6. Summary

The rapidly developing tower echo is considered as a cumulus convection. The reasons are stronger reflectivity over 10 dBZ and higher ρHV around one comparing with the turbulence CAE. Since the C-band weather radar cannot detect small cloud droplets, in which the reflectivity may be less than −10 dBZ, the cloud droplets in the cumulus convection seem to grow up into larger precipitation droplets detected by the COBRA. The horizontal scale of the tower echo is about 500 m, which is smaller than the bell-shaped echo. Since the COBRA detects only the core part with precipitation of the cumulus convection, however, the actual size of the cumulus cloud must be larger. An important point is that the tower echo develops above the bell-shaped thermal echo. This observation result indicates that a part of thermals in the ABL penetrates into the free atmosphere above the ABL, and causes the cumulus convection.

Using the C-band multi-parameter radar which can detect both turbulent echoes and precipitation echoes, the relationship between thermal in the ABL and cumulus convection is revealed. However, to investigate the detailed evolution process from thermal to precipitation through cumulus cloud, it is necessary to use a cloud detecting remote-sensor such as a high-frequency cloud radar.

References


