Frequency Modulation Continuous Wave Profiling Radar for Precipitation and Observed during 2014 TIPEXIII.

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1.Introduction

The operational weather radars, such as the U.S. WSR-88Ds and CINRAD-98D in China, cannot look vertically due to antenna mechanical constraints. The vertical pointing radar with the usual vertical looking modes different with the other atmospheric scanning radars might contribute to the current lack of synergistic observational studies.

To get a better understanding of the microphysical processes that generation and evolution in the govern precipitation cloud, there are the supplement for scanning radar measurements with multi frequency observations by other remote sensors, such as wind profiler, cloud radar, and airborne radar all of which are mostly vertically pointing. Observations from these instruments are usually presented in a height-versus-time observation.

Vertical structure is important in understanding how the distribution of latent heating affects the atmospheric circulation and how to better parameterize precipitating cloud systems in numerical models(Williams et al. 1995,2004). Understanding higher temporal and spatial changes in the precipitating clouds drive the development of radar technology. The profiling radars are ideal instruments for examining the vertical structure of precipitating cloud systems. The C band Frequency Modulation Continuous Wave Profiler (CFMCWP) has been developed by State Key Laboratory of Severe Weather/Chinese Academy of Meterological Sciences (LaSW/CAMS) in 2013.

High temporal and vertical resolution observations from CFMCWP deployed during the Third Tibaten Platurn Experiment (TIPEXIII) in the summer of 2014, were used to investigate the vertical structure and microphysical processes occurring in precipitation cloud. This article using the data observed from 1 June through 31 July on the 4508m height of Naqu Tibaten, both the detection capability of the CFMCWP instrument platforms and some characteristics of cloud vertical structure over Tibetan plateau are given

2. Equipment and Data

2.1 Instrument Introduce

Compared with pulse Doppler radar, Frequency Modulation Continuous Wave (FMCW) radar can provide detail characteristics and rapid evolutions of clouds. Pulse Doppler radar using a narrow pulse transmitting method to improve the detecting resolution, but the bandwidth reduced the sensitivity of receiver. The technology of wide pulse, narrow pulse receiving pulse compression lift the system noise level, the result is affects the detection capability. So the pulse Doppler radar is difficult to obtain higher range resolution without loss of detection ability conditions.

The distance measure of FMCW radar is modulated the transmitted continuous wave signal and demodulated for return signal. The advantage of FMCW radar system is high precision, no detecting blind zone and lower peak power.

LaSW's C band FMCW Profiler(CFMCWP) is mainly used for accurate detection of high vertical resolution in the precipitation cloud. The technology include the bistatic dual antenna system, weighted processing method of the FFT spectrum transform and sidelobe suppression. Table 1 give the main parameters specification. The spatial resolution is 15m-30m and the resolution temporal is 2s-3s ,CFMCWP can obtain the rapid evolution process of cloud and precipitation from 15m to 24km height range. The minimum detectable reflectivity are -50dBZ near surface and -25dBZ at the height of 12km. For the precipitation cloud there is no attenuation caused by stronger precipitation signal.

Table 1. Specification of CFMCWP

Parameter	**Specification**
Frequency	5530MHz ±3MHz/ ±3.5MHz
Pulse Repetition Period	600、700μs
Band width	6MHz ±3MHz/ ±3.5MHz
Typical sampling time	2s,3s
Range resolution	15m、30m
Height range	15m-12km,/30m-15km/30m-24km
Antenna	Bistatic/paraboloid
Antenna radius	1.6m
Antenna gain	≥35dB
Beam width	≤2.6°
Transmitting power	≥150W
Number of FFT	height range:512 Doppler velocity spectrum:512

2.2 data introduce

High temporal and vertical resolution data from Lasw's CFMCWP deployed during the Third Tibaten Platurn Experiment (TIPEXIII) in the summer of 2014, were used to investigate the vertical structure and microphysical processes occurring in precipitation cloud. Removal of equipment fault, power outages and other disturbing influences, the total number of 1442634 vertical profiles from ground were observed. Same representative examples provided a basis evaluating for the ability of CFMCWP observed at Naqu site in Tibetan. From these dataset, the boundary air turbulence, short lifecycle Isolated cells near ground and the deep convective cloud with the hail or graupel on the surface were given for knowledge the characteristic of Tibetan plateau. The CFMCWP instrument photo and deployed site were shown in Fig.1.

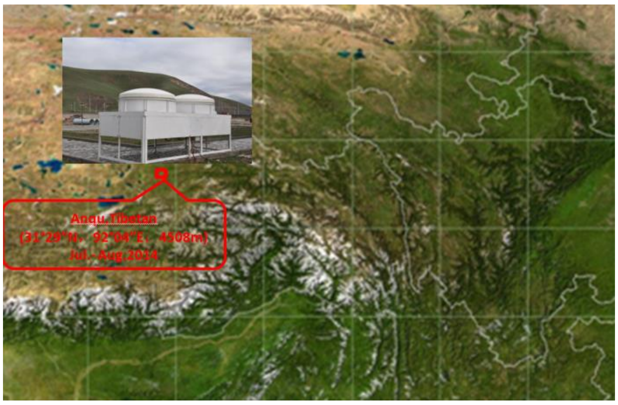

Fig.1 CFMCWP photo and deployed site Naqu(31° 29"N，92° 04"E，4508m), observed from Jul.1 to Aug.31 2014

3. Characteristic of turbulence and cloud over Tibetan

3.1 Air turbulence in boundary layer

The wind profiler working at frequency of UHF and VHF observed for the atmospheric turbulence. The S band FMCW radar developed by the A laboratory is used to study the atmospheric boundary layer.

The boundary atmospheric turbulence can be detected as reflectivity lower than -40dBZ of CFMCWP at the first gate near ground. The reflectivity of Rayleigh scattering caused by hydrometer particles ware alternated to the atmospheric refractive index structure constant C_n^2 of Bragg scattering caused by the turbulence. Time-height section of C_n^2 ,vertical velocity and speed width during 1500-1700(LT) on Jul.26, 2014 in Naqu. This phenomenon appeared from the noon to the dusk during the little cloudy days on Tibetan.

The undulation near the height of 2km may be cloud around the boundary top and internal updraft and downdraft appeared alternately. The small scale circulation regarded as air vertical motion in the boundary layer. The small circulation which the maximum updraft and downdraft ware near 2ms^{-1} can be considered as heat convective bubbles trigger by the strong radiation of cloudless from noon to dusk at plateau. The heat bubbles lifecycle lasted ware difference from one to several minutes which indicated atmosphere was extremely nonuniform inside boundary layer. The heat convection bubbles may be induced by nonuniform of the humidity and dynamic near ground, and causing the fluctuated obviously around 2km height. The height of heat convective bubbles ware restrained and the humidity aggregated continuously under the height of 2km, which may be the height of boundary top. The high frequently changed of velocity circulation has not been observed in the other regions of CFMCWP.

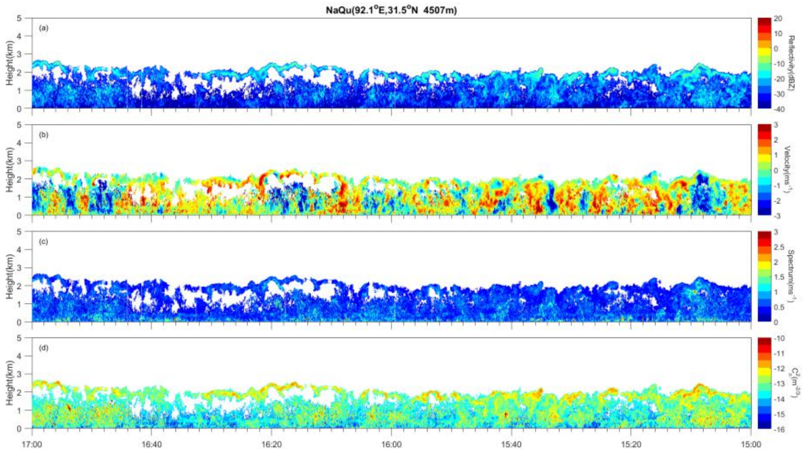

Fig.2.Time-height section of C_n^2,reflectivity,velocity and width during 1500-1700 (LT)on Jul.26, 2014.
(a)Reflectivity (b) Vertical velocity (Downward: positive, upward: negative)(c) Speed width
(d)Refractive index structure constant C_n^2

3.2 Short lifecycle cloud

The multi short lifecycle cells continuous occurred was the typical phenomenon observed from CFMCWP in the Tibetan plateau. As showed in Fig.3, the three lifecycles of weak convective cells maintained 16 minutes, 9 minutes and 12 minutes respectively. The cloud top of scattered distribution clouds over Tibetan were usually under 6 km (AGL), lifecycles from a few minutes to more than ten minutes. These isolated cells were often observed continuously CFMCWP during the period from noon to the evening.

The reflectivity characteristic of three cells in Fig.3a were differences, the intensity of first cell was weakest, the maximum reflectivity of second cell appeared at the cloud top and the stronger reflectivity in the third cell was at lower layer. Fig.3b showed vertical velocity increases near the ground were coursed by the particles melting. Compared with the weak of reflectivity radial velocity toward the ground was stronger, and only on the top of the third cell appeared weak updraft. There were showed that the atmospheric dynamic updraft were weaker in these cells.

Fig.3 showed the vertical structure characteristics of scattered, sporadic cells, these isolated small convective cells appeared more frequency after sunrise. The characterized of decentralized distribution in precipitation system over Tibetan plateau may be the environmental water vapor insufficient at higher altitude.

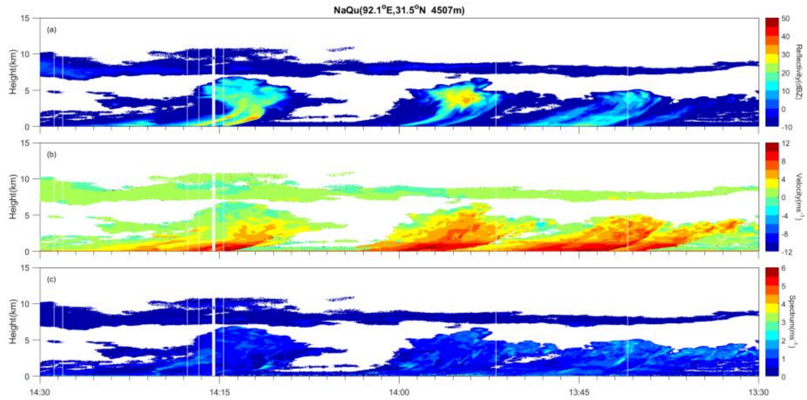

Fig.3 Time-height sections observables of CFMCWP Reflectivity during 1330-1430(LT) on Jul.05,2014

(a) vertical velocity (b) Vertical velocity (Downward: positive, upward: negative) (c) speed width

absence profiles were removed electromagnetic interference

3.3 Deep convective cloud

Many results of early research showed the vertical structure of clouds over Tibetan were higher development. Several properties were aided in the description of the cloud structure evolution with corresponding vertical cross sections of CFMCWP. As shown in Fig.4, a deep convective event which passed overhead the CFMCWP site was near two hours on Jul. 4 2014. The cloud top was arrived the height of 12km(AGL)/16.5km(ASL).

Lifecycle of three intermittent erect convective cells ware observed 38 minutes from 1743 to 1821(LT), 26 minutes from 1821 to 1847(LT)，and 18 minutes from 1847 to 1905(LT), respectively. The maximum height of the 35dBZ reflectivity extended to 8km(AGL)/12.5km(ASL) in Fig.4a. It should be noted that the large values of velocity enhanced obviously near 0.8km which well correlated with melting level shown in Fig.3b.

The hour rainfalls during 1700-1800(LT),1800-1900(LT) and 1900-2000(LT) are 0.6 mm, 8.6 mm and 1.4 mm respectively. Compared with the deep precipitation clouds, the rainfalls were not heavy but the hail observed on the ground during each convective cell period.

Above melting level, there is evidence of updrafts and downdrafts extending over height of 12km(AGL)/16.5km(ASL). Maximum updraft reached 15.8ms^{-1} near the cloud top in front of the first cell, and maximum updraft reached 18.1ms^{-1} near the middle level during the third convective cell(Fig.4b).

In order to understand the atmospheric dynamics in convective system, the air motion algorithm was applied to the deep convective cloud showed in Fig4c (Giangrande et al., 2013).

The air vertical motion calculated from the reflectivity combined with velocity a little circulation with updraft and downdraft corresponding the cell show in Fig.4a, Fig.4c. Strong updraft and downdraft occurred alternately benefited by the rarefied air over the surface of 4.5km high altitude. The enhance circulation of updraft and downdraft during deepen convection contributed to the droplets coalescence growth and broken to wide spectral distribution of particles. The hails and graupels on the ground occurred high frequently during the convection period because melting level near the ground (Fig.4a,Fig.4b,Fig.4c).

The deepen convective cells were appeared both increased near 0.8 km height for the reflectivity Z and velocity Vr, changed features similar with the particle melting process

(Fig.4a,Fig.4b). This phenomenon can be explained that no strong updraft at the lower level during the deep convective clouds. The mainly ice phase hydrometeors in cloud which implied the cold-rain processes during the Tibetan deepen cloud. The hails and graupels observed at ground is caused by which descending ice hydrometeors have not been fully melt through the 0°C temperature altitude near the ground.

The maximum updraft and downdraft were 17ms^{-1} and 13 ms^{-1} respectively, and the air vertical motion circulation center near the height of 8km(AGL). The strong air vertical circulation in the deepen convection was similar with the described of Browning (Browning et al. 1962), but circulation height was much higher than article described.

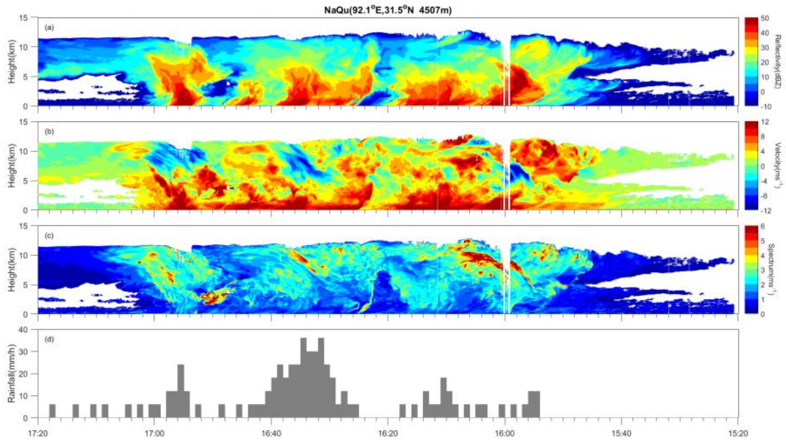

Fig.4 Time-height sections of CFMCWP (variables) during 1520-1720(LT),Jul.4 2014

(a)Reflectivity, (b)vertical velocity(Downward: positive, upward: negative),(c) air motion(same b), (d) rain intensity calculated from minute rainfall.

4. Statistical characteristics cloud structure

The statistical characteristics of reflectivity and velocity of Tibetan from the continue observation data on Jul. and Aug. were given in Fig.5. with CFAD(Contoured Frequency by Altiude Diagrams) The main characteristic of precipitation cloud is deep convection during the cold vortex monsoon season in Tibetan plateau.

The width spectrum distribution of reflectivity and the velocity was narrow over the melting level in stratiform, which indicated that different masses of solid phase particles exited, and the difference of shape and density of particles show the difference of reflectivity, but the velocity values concentrated upon the 0-5ms^{-1}.

Under height of 2km, the high frequency of reflectivity less than -30dBZ was the clear atmospheric turbulence in the boundary layer(Fig.5a,Fig.6a,).Showed in Fig.5a\b,Fig.6a\b, the reflectivity and the velocity near 1km was the height of the melting-level, and melting process in July was more obviously showed in Fig.5a.

The distribution of reflectivity and the velocity right outside the stratiform with the distinct bright band features were regarded as convective cloud(Fig.5a/5b,Fig.6a/6b). The convective activity was small proportion of observed profiles.

Compared with the total height of more than 12km(AGL), the melting level near 1km(AGL), which implied the characteristics of cloud vertical structure over Tibetan plateau were the deepen cold cloud. The another important microphysical feature aloft Tibetan was the widen distribution exceed 20ms^{-1} of velocity during the cold cloud. The up motion especially ascended over 10ms^{-1} indicated the atmospheric dynamic updraft strongly, and removed the fall velocity of particles, the larger atmospheric downdraft inside the cloud also.

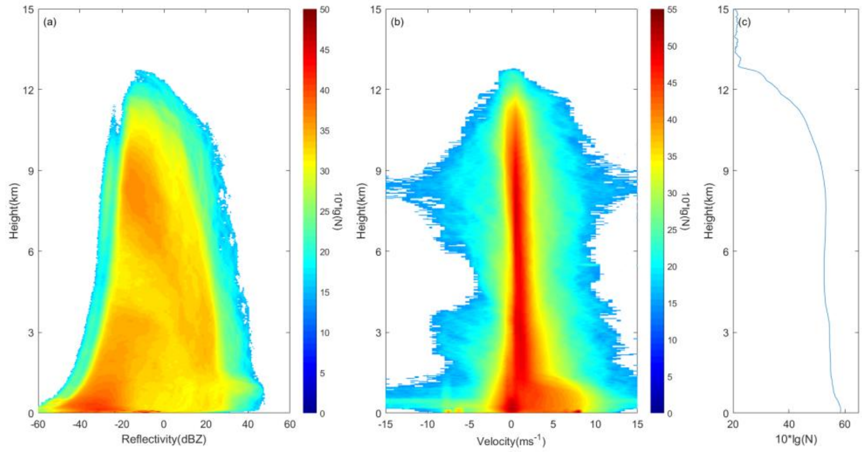

Fig.5 CFAD from continue observation of CFMCWP during TIPEX III the Jul.2014

(a) reflectivity (b) velocity(Downward: positive, upward: negative) (c) number of profiles

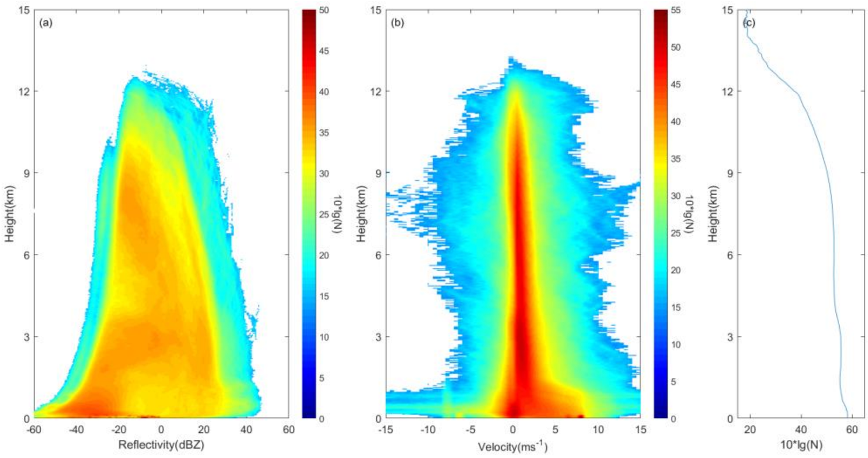

Fig.6 CFAD from continue observation of CFMCWP during TIPEX III the Aug.2014

reflectivity (b) velocity(Downward: positive, upward: negative) (c) number of profiles

5. Summary

The evolution of the fine scale vertical structure ware investigated from the higher temporal and spatial resolution of CFMCWP. From the observation of the TIPEXIII in the monsoon of 2014, the features of vertical structure in the cloud and some boundary air turbulence improved. Major conclusions from this study are as follows:

1) Benefit from observation ability near ground and detection of weak signals of CFMCWP, the small heat convective bubbles which triggered from ground were observed inner the boundary layer in the afternoon of cloudless day.

2) Like the previous case of Jun.4 2014, the structure characteristics of 28 short lifecycle weak systems were observed from CPFMCWP from July to August 2014. These events are generally presented scattered popcorn distribution observed from the scanning radar.

3) Mainly ice phase processes played important roles in producing intense rainfall in organized convection, and deep convective cell was mainly contained stronger updraft and downdraft from

middle to upper level of cloud.

4) The accumulated rainfall of 9 deep convective systems was 82.7mm and many deep convection accompanied with hail. The accumulative rainfall of 28 short lifecycle events is 28.7mm, lower contribution to the total rainfall.

The following objectives with the CFMCWP will be study later: 1) better understand the vertical structure of precipitating cloud systems in different regions, 2) estimate the vertical air motions in the precipitation clouds, 3) the microphysical processes associated with different cloud processes, and 4) atmospheric turbulence in the boundary layer.

Acknowledgements:

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