Evaluation of Cloud Observation with MMCR FALCON-I from Hedo Campaign 2008

Jun Yamaguchi[1], Toshiaki Takano[1], Youhei Kawamura[1], Hideji Abe[1]
Tamio Takamura[2], G. Pandithurai[23] Atsushi Shimizu[4], Ichiro Matsui[4]
[1]*Chiba University Graduate School of Engineering, 1-33 Yayoichou Inage Chiba Chiba Japan,*
junyamaguchi0728@graduate.chiba-u.jp
[2]*Chiba University The Center for Environmental Remote Sensing, 1-33 Yayoichou Inage Chiba Chiba Japan*
[3]*Indian Institute of Toropical Meteorology, Pune India*
[4]*National Institute for Environmental Studies, 16-2 Onogawa Tsukuba-City Ibaraki 305-8506 Japan*

Abstract
The Millimeter-Wave Cloud Radar (MMCR) is an effective tool to detect clouds. , Chiba University developed the Frequency Modulated Continous-Wave (FMCW) MMCR, named FALCON-I, at 95GHz, which provides cloud top, base height, reflectivity, and doppler velocity. Although it has provided clear and detailed radar reflectivity from many observations, the technics of MMCR still have some uncertainties which must be take into consideration for correction of radar reflectivity. This paper examines the differences between FALCON-I data and data from other meteorological tools observed during the 2008 Hedo Campaign (organized by the National Institute for Environmental Studies) and evaluate those differences to figure out what is able to be observed by FALCON-I.

1. Introduction

Chiba University Shimakura Lab. has developed a FMCW Millimeter-Wave Cloud Radar named FALCON-I at 94.79GHz with 10MHz modulated in sawtooth wave, shown in Fig.1, for measurements of radar reflectivity and cloud droplets doppler velocity. This radar has two cassegrain antennas (transmitting antenn and receiving antenna), and the main characteristics of the radar are listed in Table 1. (1)

Table 1 : Main Characteristics of FALCON-I

Center Frequency	94.79GHz (W-band)
Modulation Range	∓10MHz
Transmitting Power	0.5W (27dBm)
Range	500m – 20000m
Spatial Resolution	15m (variable)
Temporal Resolution	1sec (minimum)
Anttena Diameter	1m
Antenna Gain	57dBi
Antenna Distance	1.4m

FALCON-I has joined several observation projects which had been organized by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and National Institute for Environmental Studies (NIES). Radar reflectivity calibration was done by simultaneous observation with MMCR "SPIDER" developed by National Institute of Information and Communications Technology(2).

Fig.1 : Outlook of FALCON-I

FALCON-I provides cloud top height, cloud base height, radar reflectivity and doppler velocity. Radar reflectivity is calculated from radar equation (equ.1) from receiving power at receiving antenna.

$$P_r = \frac{\pi^3 P_t G \theta_h^2 \Delta r |K_w|^2}{2^9 (\ln 2) \lambda^2 r^2} \frac{Z_e}{A_a A_c A_r F_p} \quad \bullet\bullet\bullet \text{(equ.1)}$$

Parameters

P_r :Receiving Power (W) P_t :Transmitting Power (W) G :Antenna Gain
θ_h :Half-Power Beamwidth (rad) Δr :Range Resolution (m)
K_w :Complex Permittivity Factor of Water λ :Wavelength (m) r :Distance (m)
Z_e :Equivalent Radar Reflectivity Factor (mm^6/m^3) A_a : Atmospheric Attenuation
A_c : Cloud Attenuation A_r : Rain Attenuation F_p : Parallax Correction Factor

Although most of the parameters in radar equation are constant, the parameters of attenuation are not yet to be corrected. The attenuations which must be considered include atmospheric attenuation caused by water vapor and oxygen in the atmosphere, cloud attenuation caused by the absorption of radio waves in the clouds, and parallax attenuation that results when the radar has two antennas on different antenna axes. The parameters of these attenuations at equation 1 are expressed in Aa, Ac, Ar and Fp.

The main object of this study is to evaluate the observed data of FALCON-I by comparing with the cloud base height from LIDAR of NIES and relative humidity from the Radio-Zonde at Naha of Japan Meteorological Agency, comparing with the calculated cloud top height from brightness temperature of MODIS (MODerate Resolution Imaging Spectroradiometer) developed by NASA (National Aeronautics and Space Administration), and comparing with LWP (Liquid Water Path) observed and calibrated from Micro Radiometer.

2. Methods

2.1 Cloud Base Height

FALCON-I provides cloud base height which is decided from radar reflectivity. The cloud base height of LIDAR is used to evaluate the ability of FALCON-I to determine cloud base height. Fig.2 shows zenith radar reflectivity on April 26 in 2008 at Cape Hedo Site of NIES. High density cloud were detected until 6:00 (UTC), and weak reflectivity was constantly detected below 1km all day.

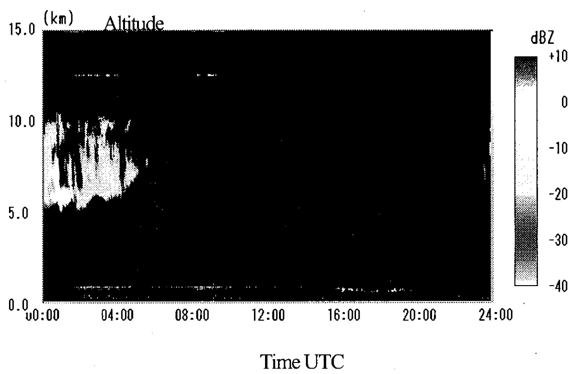

Fig. 2 : Time/Height Plot of Radar Reflectivity on April 26 in 2008

Fig.3 Shows Time/Altitude cloud base height plot of LIDAR and FALCON-I. Red-round plots are LIDAR cloud base height. Time resolution is 15 minutes. Blue-cross plots are the lowest cloud layer's base height of FALCON-I, and light blue-triangle plots are the second lowest cloud layer's base height of FALCON-I. Time resolution of FALCON-I is 1 minute. As shown in Fig.2, the observed cloud before 6:00 was thick, which leads to good matching between FALCON-I and LIDAR aroud 5-8km in Fig.3. There are also some good matching below 1km around 9:00 and 18:00 in Fig.3.

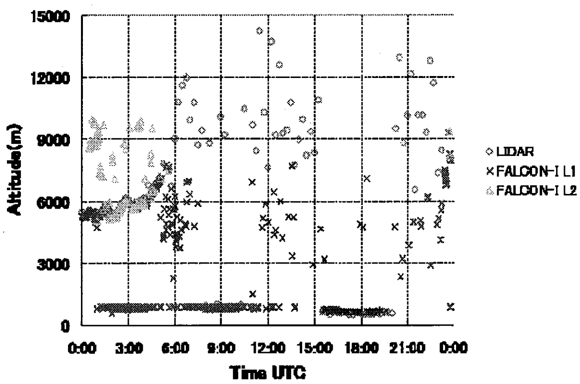

Fig.3 :Cloud Base Height Plot of LIDAR and FALCON-I on April 26 in 2008

Some plots of FALCON-I over 3000m after 9:00 do not seem reflectivity from clouds, comparing with radar reflectivity of Fig.2 and cloud base height of Fig.3. Although the resource of this reflectivity has yet to be revealed, atmospheric emission, clear-air-echo or temporary system noise of FALCON-I are one of the possibilities.

Cloud base height below 1km were never detected before 8:00 by LIDAR. On the other hand, FALCON-I detected cloud base height under 1km before 8:00. It is apparently that non-cloud echo like the echo or noise mentioned above are counted in cloud base height calculation algorithm. To avoid this confusion, the threshold of reflectivity is needed. It depends on the situation what kinds of clouds are targeted, but -30dBZ is proposed to be the threshold for many cases. It was reported that more than 80% of clouds which influences thermal emission and absorption at middle latitude areas in the north hemisphere are over -30dBZ[(2)].

Not only comparing base height, but also comparing LIDAR cloud base height and FALCON-I's radar reflectivity at cloud base height is needed to evaluate FALCON-I's sensitivity.

2.2 Cloud Top Height

FALCON-I also provides cloud top height which is determined from radar reflectivity. MODIS is one of the other useful observation instruments to evaluate cloud top height of FALCON-I. The MODIS contains several instruments which is operating on the two spacecrafts named "Terra" and "Aqua". It scans the entire surface of the earth every one to two days with measuring 36 spectral bands between 0.405 amd 14.385um, and its spatial resolutions are selectable from 250m, 500m and 1000m [(3)].

Cloud top height is to be guessed from cloud top temparture. MODIS observes around 2am over Cape Hedo almost everyday. Statistic correlation of cloud top height between FALCON-I and MODIS will be done during FALCON-I's observation period from February 17th until May 4th, 2008.

2.3 Liquid Water Path

There are several reports and methods about radar reflectivity - liquid water content (Z-LWC) relationship. Not only value are important, but also classification of clouds influences this relationship(4). The micro radiometer of Chiba Univercity CEReS (Center for Environmental Remote Sensing) set at the Hedo site provides LWP (Liquid Water Path) every three minutes. In this paper, integrated radar reflecivity from could bottom to top and liquid water path from the micro radiometer are compared in several cloud cases to evaluate correlation between FALCON-I and micro radiometer.

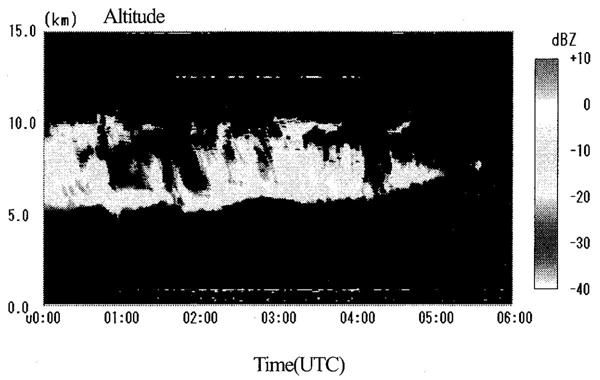

Fig. 4 : Radar Reflectivity from 0:00 to 6:00

Fig.4 shows Time/Height plot of radar reflectivity (Z) on April 26, 2008 in Universal Time. Precipitation was not detected, but thick and relatively high density clouds were observed during 0am – 6am.

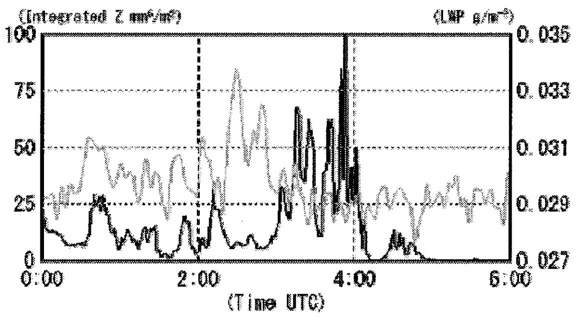

Fig.5 : Integrated Radar Reflectivity and LWP

Black line is the integrated radar reflectivity of FALCON-I and grey line is the liquid water path observed by micro radiometer.

Fig.5 shows the integrated radar reflectivity of FALCON-I and the LWP of the micro radiometer. The peaks of the both lines mitches well until 2am, but the highest peak of micro radiometer is around 2:30 and the peak of FALCON-I is around 3:50. The most important point when radar reflectivity and LWP are compared is removing the influence of ice clouds. Micro radiometer does not detect the frequencies which are emitted by ice clouds, and strong ice clouds have large reflectivity. It is guessed that most of the clouds observed before 2am are liquid water clouds and the clouds observed after 2am contained high density ice clouds. Other methods are needed to evaluate this hypothesis. Radio-Zonde data is one of the method to separate liquid region and ice region of clouds. Radio- Zonde observation was closed at March 31st, 2008 at Naha where is 100km apart from Hedo, but there might be several cases that this method can evaluate the correlation of Z and LWP.

2.4 Cloud Appearance Frequency

The several methods of evaluating FALCON-I, comparing with other meteorological observation instruments, were discussed the above. It is also needed for FALCON-I to be evaluated by meteorological common sense.

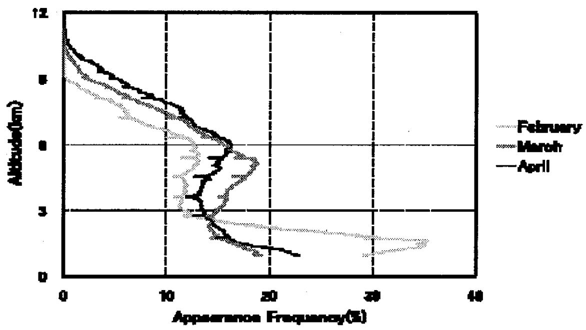

Fig. 6 : Cloud and Precipitation Appearance Frequency by Month during Observation Period.

Fig.6 shows Cloud and Precipitation Apperance Frequency by each month (Feburuary, March and April) / Height plot. Data below 1km was ignored to prevent unprecipitation or non-cloud echo from influencing the result. It is clearly seen that the highest height goes up as month goes by. Another unique point is February line has the peak at 2km, although March and April lines have the peak at the lowest height. This implies that stratus cloud or stratocumulus cloud appear more often in February in Okinawa, which strongly influence global climate because of their high albedo(5). Annual observation of MMCR might give more hints about thermal emission change of the each seasons.

3. Conclusion

There were some unique results mentioned above from FLACON-I observation. There are also useful data to evaluate FALCON-I's results. Although evaluation has just began, it is expected that new characteristics of clouds are found and some results would give hints for correction of radar equation to estimate the real radar reflectivity.

Acknowledgements

This symposium is sponsored by the Ministry of Education, Science, Sports and Culture, Japan (MEXT), and National University Corporation Chiba University.

The author would like to thank Dr. Shimizu and Dr. Matsui of NIES for providing LIDAR data and giving some guidance, Prof. Ishizaka of Aichi Gakuin University to evaluate assumed CCN (Cloud Condensation Nuclei).

References

1) Toshiaki Takano, Jun Yamaguchi, Hideji Abe, Kenichi Futaba, Shinichi Yokote, Youhei Kawamura, Tamio Takamura, Hiroshi Kumagai, Yuichi Ohno, Yuji Nakanishi, Teruyuki Nakajima : "Development and Performance of the Millimeter-wave Cloud Profiling Radar at 95GHz", IEEJ Trans, FM Vol.128, No.4 pp.258-262 (2008)

2) H. Horie, H. Kuroiwa, Y. Ohno: "Cloud Observation with CRL Airborne Cloud Radar", CRL Japan, Vol.48, No.2, pp.71-80 (2002) (in Japanese)

3) MODIS Web at homepage of National Aeronutics and Space Administration "http://modis.gsfc.nasa.gov/about/"

4) Neil I. Fox, Anthony J. Illingworth : "The Retrieval of Stratocumulus Cloud Properties by Ground-Based Cloud Radar", American Meteorological Society, Journal of Applied Meteorology Volume 36, Issue 5 (May 1997)

5) Virendra P. Ghate, Ieng Jo, Efthymios Serpetzoglou and Bruce A. Albrecht: "High Resolution Observations of Drizzle From Stratocumulus Using a 95 GHz FMCW Radar", Extented abstract at 32nd conference on radar meteorology (October 2005)