# Observations of Clouds in the Pacific Ocean with the Millimeter-wave FM-CW Radar

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**Abstract**

*In order to investigate thin, high latitude clouds, which influence gobal energy balance, we developed a low-power and high-sensitivity cloud profiling radar transmitting frequency modulated continuous wave (FM-CW) at 95 GHz for ground-based observations. Millimeter wave at 95 GHz is used to realize much higher sensitivity than lower frequencies to small cloud particles. An FM-CW type radar realizes similar sensitivity with much smaller instantaneous output power to a pulse type radar. Two 1m-diameter parabolic antennas separated by 1.4m each other are used for transmitting and receiving the wave. The direction of the antennas is fixed at the zenith. The radar is designed to observe clouds between 0.3 and 20 km in height with a resolution of 15 m.*

*Using the developed millimeter-wave FM-CW radar at 95 GHz, we have observed clouds in various areas in the Pacific Ocean and the Arctic Ocean on the Japanese scientific research vessel MIRAI since 2004. The radar provided good and sensitive data in these long-term observations. Comparison of cloud profiles in the Arctic Ocean and in the south-west Pacific Ocean clearly shows difference of cloud distribution and characteristics*

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## 1. Introduction

It is getting more important to know the global environment and the global change of climate for the human beings. It is necessary to know balance of solar energy coming to the Earth and cycle of water for the comprehension and to solve severe problems such as the greenhouse warming, the drying, the ozone holes and so on. One of the most significant features to know them is cloud. Information on 3-dimensional structures of clouds, sizes and distribution of cloud particles, dependence on size of optical characteristics of cloud particles, motions of particles in clouds, and so on are all desirable to determine the role of clouds.

Observations of clouds with radars would be the most powerful method to derive the information because of the following advantages: a) radio waves do not suffer from heavy extinction such as visible light, and consequently can investigate the interior of clouds, b) the radar technique, which is an active sensing method, has great advantage to investigate interior structures of clouds to passive methods such as total power observations of irradiance of clouds, c) Doppler measurements of clouds is applicable only to radio frequency waves.

Conventional radars operated at 5GHz can detect precipitation particles but are not able to detect particles in clouds because their sizes, less than a few tens microns, are much smaller than the wavelengths and, therefore, their cross sections are quite small. The cross sections of particles increase rapidly with frequency in Rayleigh scattering region. Radar observations of cloud particles at millimeter waves, which have been realized recently, have much more sensitive. Several groups have reported the development and preliminary observational results that demonstrate powerful performances to investigate cloud particles.

We have designed and developed a cloud profiling radar at 95GHz. The purposes of the development of the FM-CW radar are a) evaluation and verification of an FM-CW radar at 95 GHz in Japan comparing to a pulse radar, b) obtaining millimeter wave FM-CW radar techniques and algorism of data reduction, and c) contribution to scientific research on cloud physics. In this paper, we present first observational results with the newly developed cloud profiling FM-CW radar as well as design concepts and specifications of the radar.

## 2. DESIGN AND CONSTRUCTION OF THE RADAR

Whole view of the developed radar is shown in Fig.1. Diameter of each antenna is 1m.

Fig.1. The developed cloud profiling FM-CW radar at 95 GHz.

### 2.1 Principle of FM-CW Radar

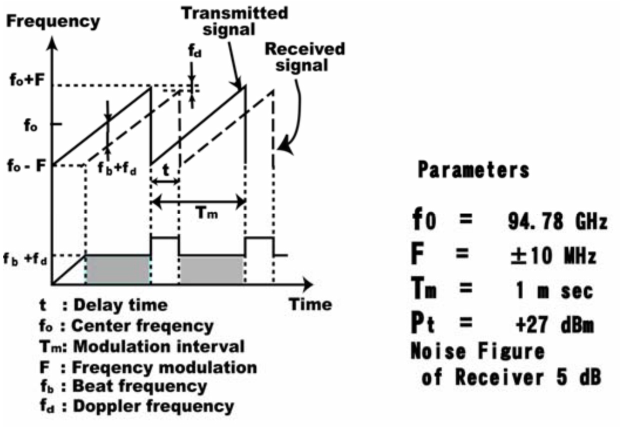
We adopt a frequency-modulated continuous wave (FM-CW) radar rather than a pulse radar because the former can achieve more sensitive system than the latter if comparing with same instantaneous output power of transmitted millimeter wave. The principle of an FM-CW radar is shown in Fig.2. The signal frequency is modulated in the range of $f_0$ +/-$F$. Transmitted signal from one of the antennas is reflected by cloud particles, returns, and is received by the other antenna with a delay time of ***t*** relative to the original transmitted signal. Mixing the transmitted and received frequencies, beat frequencies $f_b$ are observed in the spectra, which are caused by ensemble of clouds particles[1].

### 2.2 Requirements to the Radar and Outline of the System

Because one of the purposes of the facility is evaluation and verification of an FM-CW radar at 95 GHz, we design it to be a simple system so as to be developed with commercially available components and to make maintenance and upgrade by ourselves.

We designed the facility to observe clouds between 0.3 and 15 km in height with a resolution of 15 m. The velocities measured as Doppler shift should be less than 1 m/sec. The facility should be mobile for measurement at variety of places. According with the requirements described above, we decided parameters of antenna listed in Table 1[1].

The block diagram of the transmitter and receiver section is shown in Fig.3 and parameters are summarized in Fig. 2. All signals including the transmitted FM-CW signal at 95GHz and local frequencies are generated from and/or referred to two signal generators in 140 MHz range, which are synchronized to each other [1].




]Fig.2. Principle of an FM-CW radar.

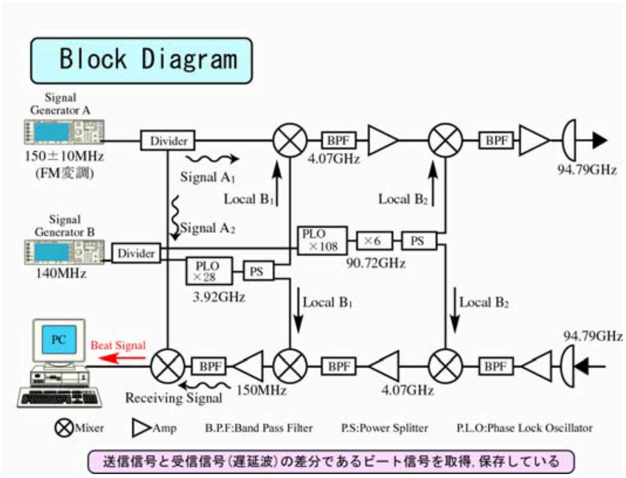



Fig.3. Block diagram of the transmitter and receiver section.

## 3. OBSERVATIONS OF CLOUD PROPERTIES ON MIRAI

### 3.1 Observations of Clouds on MIRAI in 2004 and 2005

Using the developed millimeter-wave FM-CW radar at 95 GHz, we observed clouds in various parts in the Pacific Ocean and the Arctic Ocean in 2004 to 2006 on MIRAI, a Japanese scientific research vessel operated by Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Fig.5 show s the FM-CW radar on board MIRAI and Fig.6 shows a schematic draw of the cruises.

Fig.7 shows observational results of our FM-CW radar in the Arctic Ocean in September 2004. Fig.8 shows results of the FM-CW radar and the lidar of the National Institute for Environmental Studies, Japan, operated by Nobuo Sugimoto and his coworkers[2].

Fig.5. Japanese scientific research vessel, MIRAI, operated by Japan Agency for Marine-Earth Science and Technology (upper). On boad MIRAI, developed cloud profiling FM-CW radar is settled (lower panel). Two windows on the ceiling are made of Teflon cloth.

### 3.2 Distribution of Clouds and Rain in the Arctic Ocean and the Pacific Ocean

Figs.7 and 8 show clear difference of the distribution of clouds and rain in the Arctic Ocean and in the south-west part of the Pacific Ocean. In the Arctic Ocean, clouds and rain cover almost all days in the vicinity of the sea level, while in Palau duration of rain and clouds is as short as 1 hour [2]. We investigated fraction of detecting time of clouds and rain in each height and Fig.9 shows the results. In the Arctic Ocean, clouds and/or rain cover around 50 % of time in the vicinity of the sea level and maximum height of clouds is around 6 km. In the south-west part of the Pacific Ocean, clouds and/or rain cover only 10 % and the height of clouds reachs around 10 km [2].

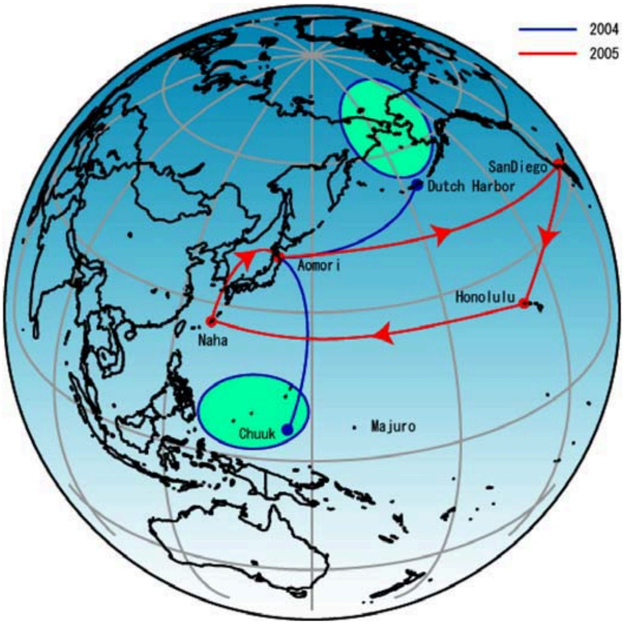



Fig.6. Tracks of the observation cruises on Japanese scientific research vessel MIRAI with the developed FM-CW cloud profiling radar at 95 GHz. We observed clouds in the Arctic Ocean and in the southwest part of the Pacific Ocean in September 2004 to February 2005, and in the northern half of the Pacific Ocean in September to January 2006.

## 4. CONCLUSION

We developed a low-power and high-sensitivity cloud profiling radar transmitting frequency modulated continuous wave (FM-CW) at 95 GHz for ground-based observations. The radar shows good sensitivity and stability during long term observations on MIRAI. The data in various area of the Arctic Ocean and the Pacific Ocean provide difference of coud distribution in these area. Further observations will present characteristics of clouds and rain in various area of the Earth and these data will b e useful for investigation global phenomena of climate.

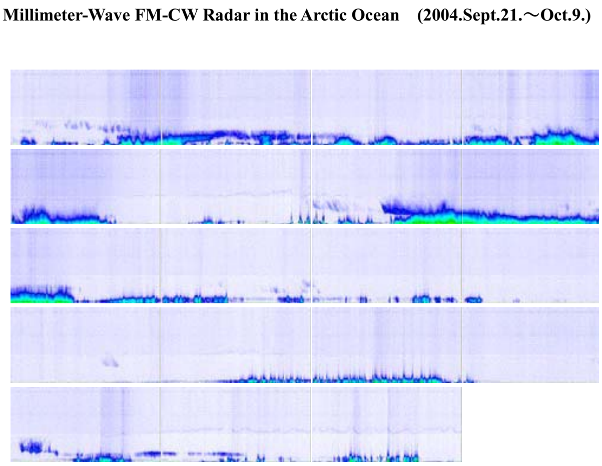



Fig.7. Observations of cloud profiles in the Arctic Ocean on September 21 to October 9 in 2004 with the FM-CW radar. Each panel shows cloud profile for one day in UT for 0 to 20 km in height. These data show that almost all days clouds at lower height are observed in the Arctic Ocean.

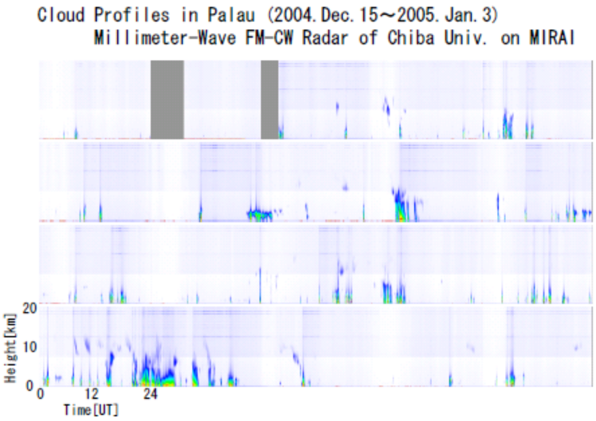



Fig.8. Observations of cloud profiles with the FM-CW radar in the south-west part of the Pacific Ocean close to Palau on December 15th 2004 to January 3rd 2005.

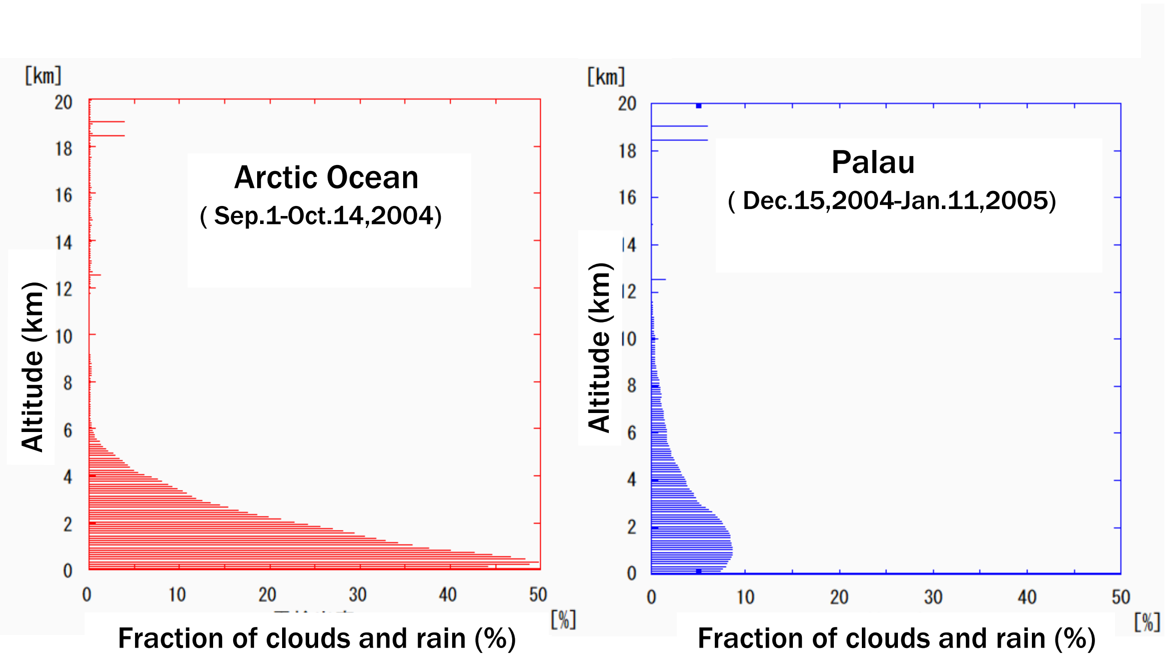



Fig.9. Observation results of fraction of detection of clouds and rain in the Arctic Ocean in September 1st to October 14th, 2004 (left panel) and in the south-west part of the Pacific Ocean close to Palau in December 15th, 2004 to January 11th, 2005 (right panel). In the Arctic Ocean, fraction of detection reach to 50% in the vicinity of the ground and macximum height of clouds is around 6 km. On the other hand, in the south-west part of the Pacific Ocean close to Palau, fraction is only 10 % and maximum height is around 10 km.

## REFERENCES

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