A 35-GHz RADAR FOR CLOUD AND PERCIPITATION STUDIES IN CHINA

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1. INTRODUCTION[1]

With the recent emphasis on understanding the role of clouds in the global radiation budget, cloud detection becomes more and more important. Although there are optical remote sensing techniques (e.g., satellite lidar, ceilometer, etc.) to measure cloud properties, optical signals cannot penetrate into thick cloud to observe the cloud's horizontal and vertical dimensions and its internal structure.

The scope of radar meteorology has expanded to include measurements of cloud properties and structure for radar's wavelength is close to cloud's diameter. Millimeter-wavelength radar is recognized as having the potential to provide a more sensitive probe of cloud particles ranging from a few micrometers in diameter to precipitation drops. Since the backscatter cross section of tiny drops (i.e., several tens of micrometers in diameter) increases in proportion to λ^{-4}, where λ is the radar wavelength, cloud drops are more easily detected by radars of millimeter rather than centimeter wavelengths. On the other hand, attenuation of millimeter waves is much stronger, and the λ^{-4} advantage gained using millimeter waves is offset by the strong attenuation these waves experience. The 10-cm-wavelength radar, used principally for storm warnings, can't detect weak and no precipitation clouds well, compared with the 8.6-mm-wavelength radar described in this paper. Because there are several strong absorption bands at millimeter wavelengths, observations are practical at few spectral windows (i.e., λ = 8.6, 3.2, 2.14, and 1.36mm). But, high-power millimeter wavelength radars are only affordable at λ = 8.6 and 3.2 mm.

Several 35-GHz research radars have been developed for the purpose of cloud observation (e.g., Pasqualucci 1983, 1984; Hobbs et al. 1985; Krofli 1994). Sekelsky and McIntosh(1996) and Mead et al.(1994) describe multiparameter radars for frofiling clouds. The radar is also used to measure drop-size distributions (e.g., Pasqualucci, 1975) and other physical parameters, such as cloud liquid water content and effective radius (Atlas, 1954; Sauvageot and Omar, 1987; Fox et al., 1997; Baedi, 2000). A radar operating at 35-GHz was designed and assembled primarily for observation of clouds and precipitation by 2007. This is the first millimeter-wavelength radar with polarization and Doppler capability used for

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clouds research in China.

The traditional application of radar in meteorology has focused on the detection and analysis of the structure and intensity of precipitation. These studies focused on classifying cloud types, establishing delectability limits, detecting cloud top and base heights, describing cloud morphology, and estimate cloud liquid water content. This paper is composed of several parts, including the radar system, data and signal processing techniques such as signal integrator and signal auto-covariance estimator, the minimum detectable signal and cloud detection, and the applications on cloud and precipitation. We will give the results of observations of a number of clouds and precipitation structures, including marine stratocumulus, cirrus, which shows the capability of this radar. Also presented are the liquid water content and the effective radius retrieved by radar.

2. RADAR SYSTEM

a. General description

The State Key Laboratory of Severe Weather (LaSW) of CAMS (Chinese Academy of Meteorological Sciences) has developed a new Doppler radar operating at 8.6 mm wavelength and incorporating a dual-polarization and Doppler capability. The radar is vertically pointing and operates at a frequency of 34.7GHz. The transmitter operates with a peak power of ~ 140kW at a pulse repetition frequency of 1000Hz. Radar system parameters are listed under below.

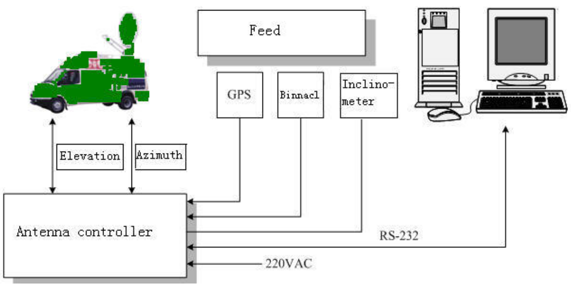


FIG.1 Equipment theory

TABLE1. Performance characteristics

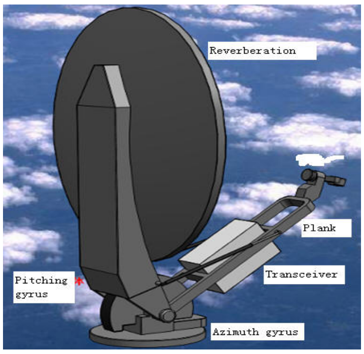
Frequency, wavelength	35GHz, λ =8.6mm
Unambiguous range	30 km
Antenna type	1.5-m diameter
Antenna gain	50 dB
Beamwidth	$0.45°$
Polarization	Linear horizontal
Beam directions	$0\sim360°$ azimuth, $-2°\sim90°$ elevation
Rotation rate	$36°$ s^{-1} azimuth, $6°s^{-1}$ elevation
Pulse repetition frequency	1 KHz ~ 3 KHz
Peak output power	$> 600W$
Pulse width	$0.3\mu s$ $1.5\mu s$ $20\mu s$

b. Dopplerization and Polarization

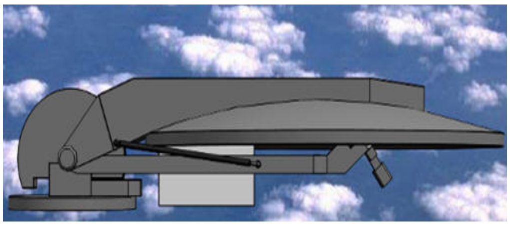
The use of Dopplerization and polarization diversity in incoherent radars (McCormick and Hendry, 1975; Seliga and Bringi, 1976) has opened new horizons in the field of remote sensing of the microphysics of clouds and precipitation. Again, recent advances in microwave technology allow polarization techniques to be incorporated in millimeter-wavelength radars. The radar described in this paper has Dopplerization and linear-polarization capability.

c. Antenna

The antenna is equipped with a 2-m-diameter parabolic antenna with an antenna gain of 50dB and a 3-dB beamwidth of 0.3°, resulting in a spatial resolution in the measurements.



(a)

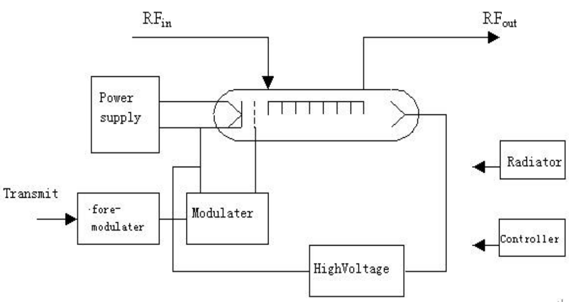


(b)

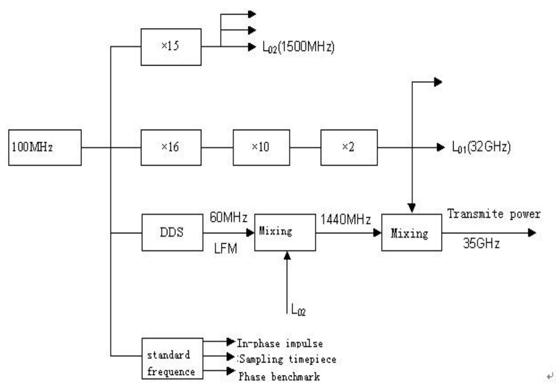
FIG.2 Antenna on (a) and off (b)

It scans according to a programmable sequence over 360° for full azimuthal coverage, or over azimuthal sectors, with elevation angles ranging from $-2°$ to $+90°$. The maximum azimuth and elevation rotation rates are 36° s^{-1} and 6° s^{-1} for azimuth and elevation directions, respectively. Also, it will fold down when radar doesn't work. This can help the antenna to keep away from the dust (Fig.2 (b)).

d. Signal processing



(a)



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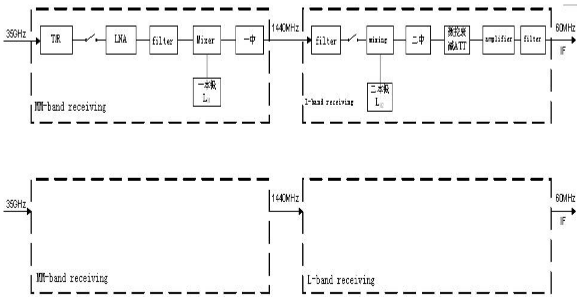


(c)

FIG.3 Transmitter system(a) and receiver system(c)(d).

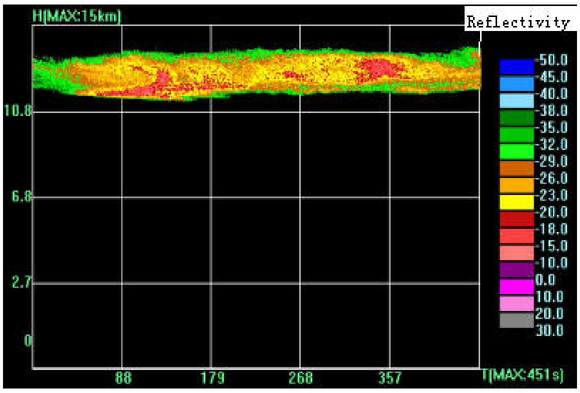
Two intermediate frequency received by radar will be imported into the receiver to process with A/D、digital frequency conversion、creating horizontal IH,QH and vertical IV,QV digital signals. With using PPP or FFT technique to process the two signals, some parameters about radar reflectivity Z, mean velocity V, velocity spectrum width, and LDR can be output.

3. APPLICATIONS OF CLOUD AND PRECIPITATION

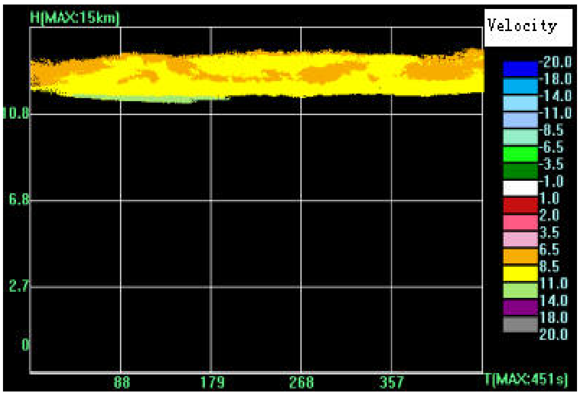
a. Radar base products of high clouds

This radar can detect four base parameters including radar reflectivity, Doppler velocity, Doppler spectrum width, and LDR.

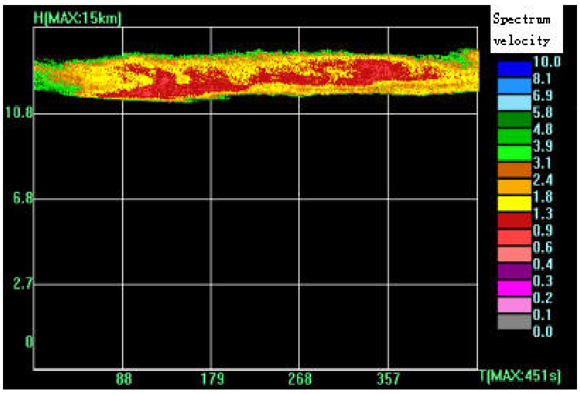
Fig.4 shows a detection about high clouds in winter.



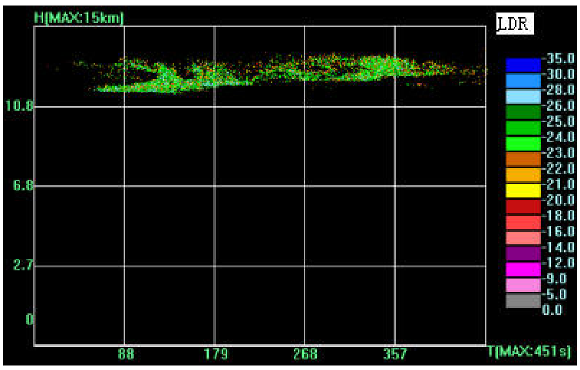
(a)



(b)



(c)



(d)

FIG. 4 Radar base products detected from high cloud: Reflectivity (a), Velocity (b), Doppler spectrum width(c), LDR (d).

b. Cloud top and base height

The radar was pointing vertically. For lower cloud, it's probably to retrieve top and base height using radar reflectivity.

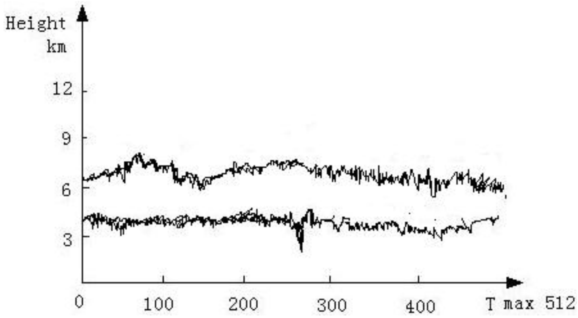


FIG. 5 Cloud top and base height

c. Clouds phase

Since particle size distribution, shape, and fall orientation are interrelated, droplet phase can be classified by radar's polarization capability (Sassen, 1991; Doviak and Zrnic, 1993; Sassen and Benson, 2001; Cao and Liu, 2005), such as one of the linear polarization measurements LDR, which is identified as:

$$L_{DR} = 10\lg(Z_{HV} / Z_{HH})$$

Z_{HV} is the radar reflectivity factor determined by transmitting a vertically polarized signal while measuring the horizontally polarized portion of the backscattered signal. Z_{HH} is the radar reflectivity factor determined by transmitting a horizontally polarized signal while measuring the horizontally polarzed portion of the backscattered signal.

Here, we use parameter V, Z, and L_{DR} to classify water and ice clouds.

d. LWC and r_e

In general there are several different ways to derive the liquid water content and the effective radius of water clouds from ground based remotely sensed data. For single radar technique, a quadratic relationship between reflectivity and liquid water content and effective radius has been established by the formers. (Atlas, 1954; Sauvageot and Omar, 1987; Baedi, 2000.) This relationship was derived by calculating reflectivities from in situ airborn droplet size measurements and relating them to the calculated liquid water content. In this study we retrieved the LWC and r_e for non and weak precipitating water cloud according to the classic relationship.

Classic relationship

Firstly, we assume a gamma distribution over a range of number concentrations N(D):

$$N(D) = AD^{\beta}\exp(-bD)$$

Where D is the droplet radius and A、β、b are the spectrum parameters. We have got a relation between radar reflectivity Z and the spectrum parameters like:

$$Z = A\frac{(\beta+6)!}{b^{(\beta+7)}}$$

also have we another relation between LWC and the parameters:

$$LWC = \frac{\pi\rho A}{6}\frac{(\beta+3)!}{b^{(\beta+4)}}$$

$$r_e = \frac{\beta+3}{b}$$

Then Z-LWC and Z-r_e is established easily.

$$Z = \frac{9}{2\pi^2 kN}\frac{(\beta+6)!}{(\beta+3)!(\beta+3)^3}\frac{LWC^2}{\rho^2}$$

$$LWC = \left(\frac{Z}{a}\right)^{1/b} \qquad r_e = \left(\frac{Z}{c}\right)^{1/d}$$

Table 2 gives a and b value in Z-LWC relationship got by the former scientists.

TABLE2. Classic value of a and b in Z-LWC

	a	b
Atlas(1954)	0.048	2.00
Sauvageot and Omar(1987)	0.030	1.31
Fox and Illingworth(1997)	0.031	1.56
Baedi et al. (2000)	57.544	5.17

4. SUMMARY

A dual-polarization pulse Doppler radar system has been described. The radar uses only one antenna for the transmitter and the receiver, and operates at 8.6mm wavelength with a transmitted peak power of 100kW. The receiver and the data acquisition and processing system allow dual-polarization measurements. Different scan modes can be selected to match the experimental requirements.

Reflectivities and extinction rates were calculated for a wide range of cloud conditions using observed liquid water contents and droplet diameters and assuming gamma distributions. These calculations indicate that the radar, with capability to detect reflectivities as low as -43dBz at a range of 1km, should give returns for nearly all boundary layer status and cumulus but may be unable to detect most altocumulus.

In this article, we Give results of radar base products, cloud top and base height, water and ice clouds, and liquid water content and droplet effective radius. Results of observations of a number cloud structures, including marine stratocumulus, cirrus, and stratus and cirrus are also described.

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