3.6 DEVELOPMENT OF CLOUD PROFILING RADAR FOR EARTHCARE

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1. INTRODUCTION

Global three-dimensional cloud distributions and their properties (liquid/ice phase, optical depth, drop sizes, etc.) are important information to estimate the earth radiation budget more precisely. The interactions between cloud particles and aerosols are also focused to improve accuracies of climate model. In order to meet expectations of scientists developing climate models for global warming problem, European and Japanese space agencies plan to launce a satellite called EarthCARE (Earth Clouds, Aerosols and Radiation Explorer). A Cloud Profiling Radar (CPR) is installed on this satellite as a main sensor to observe clouds. Comparing with optical sensors, millimeter wave radar can penetrate upper thick clouds and observe cloud or rain layers below it. In this paper, design and development state of EarthCARE CPR are introduced.

2. EARTHCARE MISSION INSTRUMENTS

EarthCARE mission, proposed by European and Japanese scientists, has been selected for implementation as sixth Earth Explorer Mission of European Space Agency's (ESA) Living Planet Program. The mission focuses on clouds and aerosols effect on the earth radiation flux budget. For this purpose, vertical structure of clouds and aerosols are important as well as horizontal distributions of clouds on global (Figure 1). Two active sensors, cloud profiling radar (CPR) and lidar (ATLID) are planed to be installed as well as optical imager (MSI) and broad band radiometer (BBR).

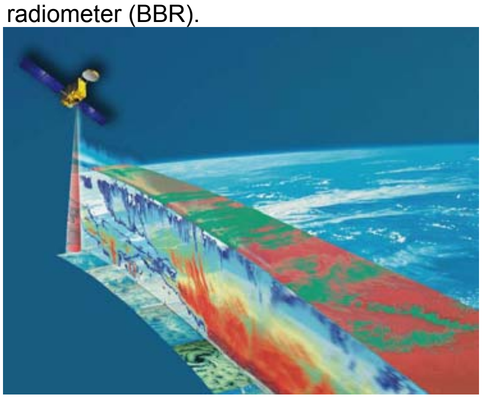

Fig. 1 Schematic drawing of EarthCARE observation

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CPR has much sensitivity to cloud particles than meteorological weather radar, so CPR can detect most of radiatively important clouds in global region. Powerful effectiveness of CPR has been already displayed by CloudSat, which installs first millimeter wave radar in space. Following this success, CPR on EarthCARE is expected to bring new important information on various clouds on earth.

ATLID is single wavelength lidar operating in the UV (355 nm) with a high spectral resolution receiver. Using high resolution filter, the backscatter signals from particle (Mie) and from molecular (Rayleigh) are separately detected. Minimum detectable optical depth of ATLID is 0.05 and its height resolution is less than 100 m. ATLID can detect aerosols and thin cloud. Synergy observation with CPR, ice water content of ice cloud can be estimated.

MSI is Multiple-spectral Imager which has one channel for visible and six channels for infrared. MSI has 150 km swath with 500 m horizontal resolution. MSI provides horizontal optical image to support active instruments.

BBR is radiometer for measuring outgoing short wave and long wave radiation at the top of atmosphere. In order to measure accurate radiative flux including angular dependency, three instantaneous radiances along satellite track (+/- 55 degrees and zenith) will be measured. TOA flux will be reconstructed from three instantaneous radiances using Angular Dependency Models.

Comparing with NASA's formation flight satellites (CloudSat CALIPSO etc.) called as A-train, one of the excellent advantages of EarthCARE is that four instruments will be loaded in the same platform. It can ensure the synergy observations between instruments. Synergy configuration and synergistic use of instruments are shown in Figure 2 and 3.

The satellite orbit of EarthCARE is frozen and sun-synchronous and the mean local solar time is within 13:30 to 14:00 in dayside. Assumed average geodetic altitude is 387 - 440 km. Orbital duration is about 90 minutes. Revisit cycle has not been decided yet.

ESA will develop three sensors (ATLID, MSI, BBR) and satellite and Japanese (JAXA and NICT) will develop CPR. Detail information on CPR will be shown in next section.

3. OUTLINE OF EARTHCARE CPR DESIGN

Table 1 is specification of CPR. Figure 4 shows EarthCARE CPR outside and Figure 5 shows block diagram. EarthCARE CPR is millimeter-wave radar which has high sensitivity. Radar frequency is the same as CloudSat CPR (94GHz), but radar sensitivity is about ten times better because of the lower orbit and bigger antenna size. EarthCARE CPR is anticipated to detect 98 % of radiatively significant ice clouds and 40 % of stratcumulous. Minimum radar reflectivity of EarthCARE CPR is -35 dBZ at TOA in condition of 10 km integration. The transmit pulse width is 3.3 micro seconds, which is the same as CloudSat. Sampling interval is 100 m, which is 250 m in CloudSat. Vertical range of observation will be 20, 16, 12 km depending on the latitude. Minimizing observation window is necessary to achieve higher pulse repetition frequency (PRF) for accurate Doppler measurement. Then valuable PRF, which is adapted with satellite height change in latitude, is adopted. Figure 6 shows an example of PRF variation with latitude.

Footprint size of CPR is about 700 m at ground. In order to good SNR and reduce data size, horizontally averaged data with along track of 500 m are minimum pixel size.

Producing big size antenna of 2.5 m is challenging issue. Accurate and light weight antenna is needed for space borne millimeter radar. An antenna made of Carbon Fiber Reinforced Plastic (CFRP) is produced on trial now. Accuracy, strength, thermal feature will be confirmed using this CFRP antenna model.

Extended interaction Klystron (EIK) is used for power transmission tube of CPR, same as CloudSat CPR. In order to achieve long term mission, EIK design is modified and its performance is checking now.

Quasi Optical Feeder (QOF) is adopted as same as CloudSat CPR. QOF will work as circulator which keep isolation between receiver and transmit ports. We confirmed good electrical feature of QOF using breadboard model. In stead of linear polarization, circular polarized radio will be transmitted to the nadir to reduce loss in QOF.

Low Noise Amplifier (LNA) is key component to get good sensitivity. In order to achieve small noise figure (NF), new LNA is developing for the EarthCARE CPR. For reducing NF of the LNA, active cooling of the device is being studied now.

Hot and cold load for receiver gain calibration are installed inside of the receivers. Two loads and antenna will be switched by ferrite switch.

Two transmitters and receivers will used for CPR to reduce risk of failure, including EIK and data processor. Primary and redundancy system are switched by rotation mirrors in QOF.

4. DOPPLER MEASUREMENT OF CPR

Unique feature of EarthCARE CPR is vertical Doppler measurement function. Vertical Doppler measurement is very attractive function from point of view of science, because vertical motions of cloud particles are related with cloud microphysics and dynamics. However, from engineering point of view, Doppler measurement form satellite is challenging technology.

Pulse pair method will be used for Doppler measurement. High coherency and high SNR is needed to get accurate Doppler measurement (Kumagai et al., 2003).

Since satellite speed is so fast (7200 km/sec), beam tilting angle from the nadir should be keep very small. Accurate antenna pointing and pointing knowledge are key technology to get accurate Doppler measurement. Doppler bias error reduction is considered to using surface echo Doppler information.

CPR/EarthCARE will try to measure vertical Doppler velocity of cloud echoes, which are important for cloud physics and drizzle detection.

Non-uniform beam filling of the beam is also affect Doppler measurements error because forward or backward bias inside of beam will make Doppler bias (Schtgens, 2007).

5. STATUS OF CPR DEVELOPMENT

This year, EarthCARE CPR project has been reviewed by Japan side. After passing several reviews, Experimental Model production of CPR will start next year. Because of tight schedule, several critical components (EIK, LNA, etc.) are developing ahead. In order to get better sensitivity and better Doppler accuracy, detail designs of the CPR are studied now.

6. REFERENCES

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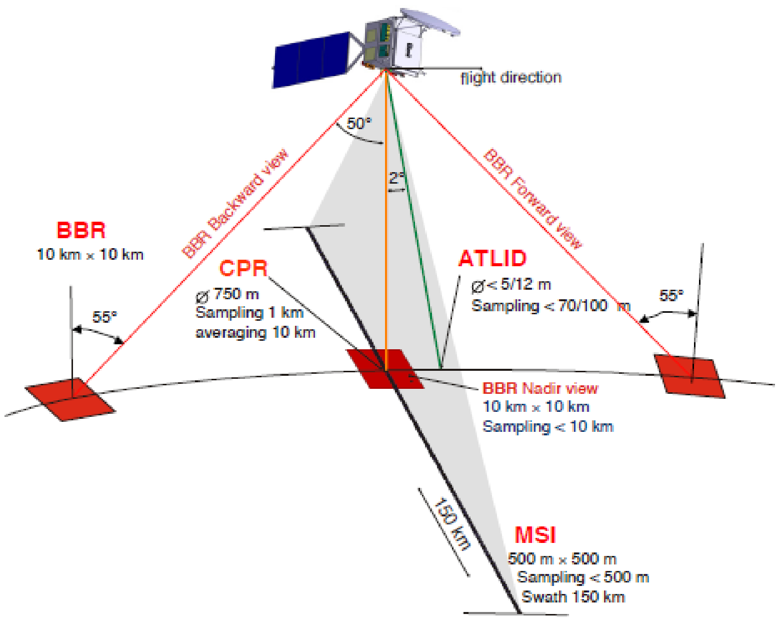

Fig.2: Configuration of synergy observations of EarthCARE four instruments

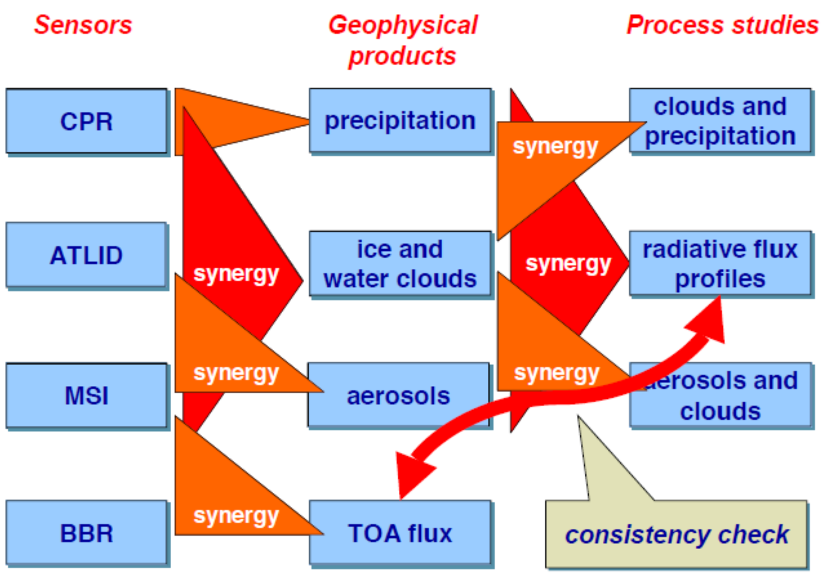

Fig.3: Conceptual block diagram for explaining synergy observation of four instruments on EathCARE

Table 1 Specification of EarthCARE CPR

Term	Value
Tx frequency	94.05 GHz
Tx peak power	1.8 kW
Pulse width	3.3μs
Antenna diameter	2.5 m
Beam footprint size	700 m
Beam direction	Nadir
Minimum sensitivity	-35 dBZ (10km average)
Data sampling volume	100 m (Vertical) 500m (Horizontal)
Doppler function	Pulse pair

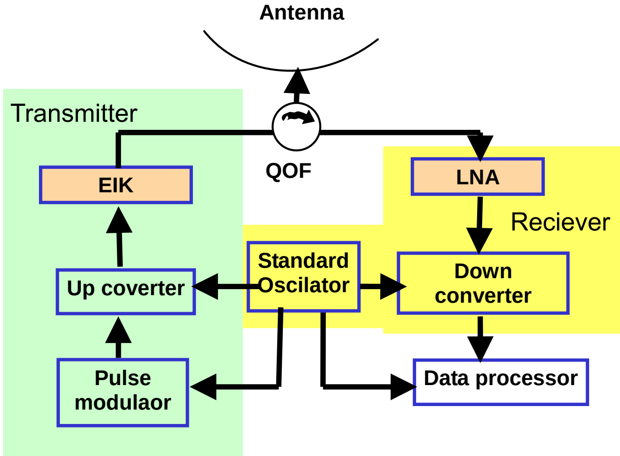

Fig.5: Block diagram of EarthCARE CPR

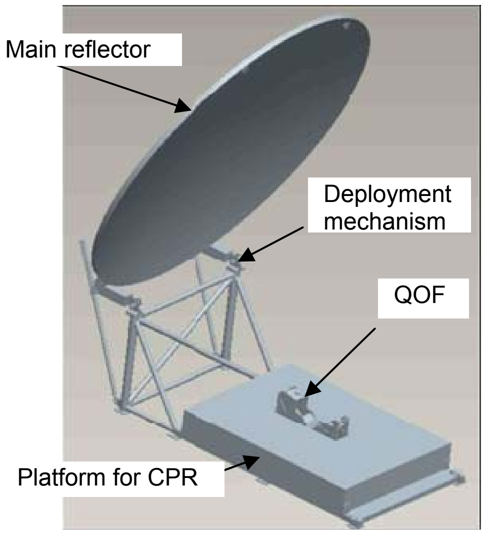

Fig.4: Outline of EarthCARE CPR

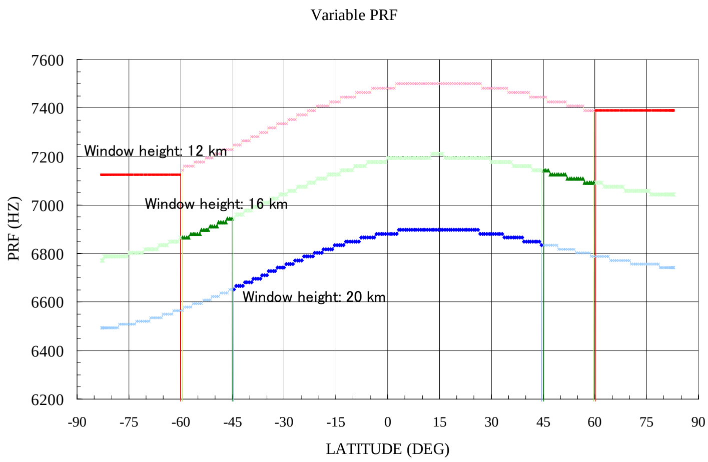

Fig.6: Example of variable PRF with latitude
Height range 12km above 60 degree
Height range 16km in 45-60 degree
Height range 20km below 45 degree