EXTERNAL CALIBRATION METHOD USING SEA SURFACE SCATTERING FOR SATELLITEBORNE W-BAND CLOUD PROFILING RADAR

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ABSTRACT:

The EarthCARE project is the joint mission between Europe and Japan, in order to measure Earth radiation budget. There are four sensors on the satellite, which are Cloud Profiling Radar (CPR), High resolution spectral Lidar (ATLID; Atmospheric Lidar), Multi-Spectral Imager (MSI) and Broad Band Radiometer (BBR). The CPR is developed under the cooperation between National Institute of Information and Communications Technology (NICT) in Japan and Japanese Aerospace Exploration Agency (JAXA). CPR uses W-band frequency and 2.5m diameter of large antenna dish in order to obtain -35dBZ in sensitivity. As the result of large antenna, the beam footprint is very small and to give up antenna scanning. It is recognized the difficulty of external calibration using active radar calibrator (ARC).

One solution of external calibration is that ARC puts on exact location of sub-satellite track. Precise sub-satellite track prediction is necessary. Another solution is using scattering from natural distributed target, such as sea surface. In this paper, we focus second solution. The CPR are requested satellite operation for roll angle maneuver in order to obtain the reflect signal from sea surface at various incidence angles. The wind speed is estimated by itself because no instrument nor simultaneous observation for wind speed for EarthCARE. The calibration accuracy analysis is performed using satellite wind speed data, such as AMSR-E radiometer. We had prospect to obtain enough accuracy by external calibration using sea surface. The feasibility of this calibration method is discussed.

1. INTRODUCTION

The Cloud Profiling Radar (CPR) on EarthCARE satellite is developed under cooperation of National Institute of Information and Communications Technology (NICT) and Japanese Aerospace Exploration Agency (JAXA) in Japan.

CPR has two objectives, which are to measure vertical profiles of clouds reflectivity and to measure up/down velocity of clouds. Then the requirement of sensitivity is -35dBZ after 10km integration and the requirement of Doppler velocity measurement accuracy is less than 1 m/s after 10km integration for more than -19dBZ of clouds. Therefore CPR uses W-band frequency and needs a large (2.5m) antenna reflector in order to obtain enough sensitivity. As this result, the footprint of CPR is very small footprint and antenna scanning capability is not implemented in addition due to too large antenna reflector.

There are similar radars in space, which are CloudSat/CPR (Stephens 2002) and TRMM/PR (Precipitation Radar). CloudSat is provided similar CPR to EarthCARE/CPR, but major difference is that Doppler velocity measurement capability is not provided for CloudSat/CPR. TRMM/PR is slightly different because its target is precipitation. TRMM/PR is uses Ku-band (14GHz) frequency and antenna scanning used by phased array antenna. Its swath is about 200km.

Usually the instrument in space needs various calibrations to convert from measured data to physical values. Then instrument has equipment inside to calibrate itself. In addition to this, external calibration is necessary to confirm overall performance. There are some external calibration methods using calibration target which reflectivity is already known. One method is using point target such as corner reflector, active radar calibrator. Another method is using naturally distributed two dimensional targets such as sea surface, desert, rain forest, snow field and so on. The problem of the first method is that it is difficult to place the ARC to exact position or to calculate the exact position of sub-satellite track. The feasibility of this method is already reported (Horie 2009). In this paper, we concentrate the second method using sea surface scattering.

The NRCS is expressed as a function of radio wave frequency and wind condition over ocean (Masuko 1986). The contribution of wind direction is neglected for near nadir condition and NRCS can be expressed as a function of wind speed (Valenzuela, 1978). Many relationships between wind speed and NRCS have been reported (Masuko, 1986; Jackson, 1992; Okamoto, 2002; Freilich, 2003). Using TRMM/PR (scanned precipitation radar in space), Okamoto et al. (Okamoto, 2002) found that NRCS for incidence angles of 5 degrees has minimum standard deviation and that the sea surface can be useful for satelliteborne radar calibration.

The pointing of CPR is nadir and it is suitable for the observation of cloud, and it is also suitable for Doppler measurement. But it is worse for NRCS measurement because surface return is sometimes specular reflection. The specular reflection is not able to predict. For the external calibration, NRCS data at slightly tilt incidence angle from nadir is needed, so we propose that satellite attitude is changed for roll angle while external calibration, but roll angular velocity is limited. Then the feasibility study of sea surface calibration accuracy is performed and reported in this paper.

2. CPR OVERVIEW

EarthCARE/CPR is the first W-band Doppler radar in space. The center frequency of 94GHz is selected to penetrate deep into the clouds from the orbit and retrieve the cloud vertical profiles including overlapped structure. The aperture of the main reflector is the largest for W-band instrument on Earth observation satellite to have high antenna gain and narrow beam width. Small footprint is necessary for enough accuracy of Doppler velocity measurement. The beam width must be as

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narrow as possible and pulse repetition frequency (PRF) must be as high as possible, in order to achieve good Doppler velocity measurement accuracy (Kumagai, 2003).
The clouds observation height of CPR is up to 20km from the ground. Observation height can be switched from 20 km to 16 km or 12 km to achieve high PRF. Default setting of observation height for nominal operation is 20 km within 60 degrees in Latitude and 12 km otherwise. Vertical resolution is 500 m, but 100 m over sampling is performed to obtain enough data for inversion as for higher level product. Horizontal integration is about 500 m and beam foot prong is about 800 m, so horizontal resolution becomes 900 m. Sensitivity which requirement is -35dBZ is defined as 10km integration and for uniform clouds. Major characteristic of CPR is shown in Table 1.

Table 1 Major specification of EarthCARE/CPR

Items	**Value**
Frequency	94.05 GHz
Peak Tx Power (EIK)	1500W (End of Life)
Pulse Width	3.3 us
PRF	6100Hz to 7500Hz
Antenna Diameter (Footprint)	2.5 m (circular) (800 m)
Cross-Track Resolution	800 m
Along-Track Resolution	900 m (500 m integration)
Vertical Resolution (Sampling)	500 m (100 m)
Sensitivity	-35dBZ @10km integration
Doppler Velocity Meas. Range	±10 m/s
Doppler Velocity Meas. Accuracy	1 m/s @10km integration, -19dBZ
Observation Height	20km, 16km, 12km (switchable)

The CPR has two calibration modes in addition to nominal operation mode. One mode is internal calibration mode which calibrates mainly receiver linearity. Another mode is external calibration mode which calibrate absolute gain of instrument or bias number. The external calibration mode consists of two different modes. One is named "external calibration mode" for using active radar calibrator (ARC) calibration, and the other is named "sea surface calibration mode" to measure the normalized radar cross section (NRCS) of the sea surface at various incidence angles. At this mode, the satellite tilts its roll angle about 0 to 10 degrees, so called roll maneuver mode.

3. SEA SURFACE SCATTERING THORY

The sea surface NRCS (σ0) is given in general, as a function of radio wavelength and polarization, wind direction and speed, and incidence angle of radio wave with respect to sea surface (θ) (Jackson 1992). A scatterometer such as SeaWINDS on QuikSCAT, which can measure wind speed and wind direction, uses such a relationship (Schroeder 1985). For incidence angles under 20 degrees, the σ0 is dominated by quasi-specular scattering and by Bragg scattering otherwise (Masuko 1986). So, far near nadir observation can be used for the σ0. In the case of near nadir scattering, the dependency on the wind direction can be neglected. It is assumed that the sea surface is isotropic and the probability density function is only a function of the mean-square slope s2, so σ0 is simply expressed as (Valenzuela, 1978),

$$\sigma^0(\theta) = \frac{|R(0)|^2}{s^2} \cdot \frac{1}{\cos^4\theta} \exp\left(-\frac{\tan^2\theta}{s^2}\right) \qquad (1)$$

where R(0) is the normal-incidence Fresnel-reflection coefficient. s2 is considered a function of wind speed (Cox 1954; Freilich 2003). For example, Cox and Munk (Cox 1954) show an empirical relationship, s2=0.005+0.512×10-3×u, where u is the wind speed (m/s).

4. SEA SURFACE CALIBRATION SCHEME

The CloudSat is already operated in space. The external calibration method of CloudSat is to observe sea surface at 11 degrees in incidence angle. From their airborne experiment, NRCS is almost constant with moderate wind speed (Li 2005; Im 2007). The wind speed can be measured by microwave radiometer. CloudSat is the one of members for formation flight called "A-Train" by NASA. The AMSR-E on AQUA satellite is operated as "A-Train" Therefore CloudSat obtains almost simultaneous observation data for sea surface wind.

While EarthCARE does not have a plan for formation flight and wind speed data cannot be available for simultaneous observation. Consequently, the CPR on EarthCARE estimate wind speed by itself using Equation 1 and observed NRCS data with various incidence angles. The parameter s, ex. R(0), s2, in Equation 1 are obtained our airborne experiment (Horie 2004). Then absolute value of NRCS is obtained from estimated wind speed using Quasi-specular scattering model expressed the equation 1.

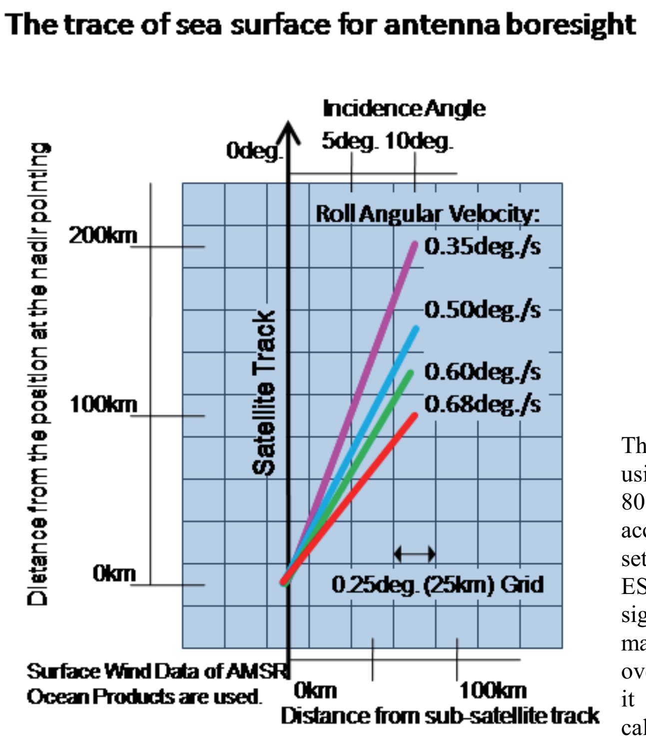
The problem of this method is assumed that the angular speed of roll maneuver of satellite is limited and observation area over ocean maybe too large area to be assumed constant wind speed. The angular velocity of roll angle is requested from 0.60 to 0.68 degrees in each second due to move half antenna beam width in pointing during 500 m integration period, but 0.50 degrees/second or 0.35 degrees/second of roll angular velocity are proposed by satellite side. So the feasibility study is needed. The accuracy of this estimation should be discussed.

5. EVALUATION METHOD

While the incidence angle is moved from zero to 10 degrees, satellite moves about 100 to 200km, and antenna pointing is about 100km far from sub-satellite track. Generally, wind speed over these area is not assumed at constant. In order to investigate wind speed variation, wind speed data obtained microwave radiometer are used. They are provided 25km square grid data. The wind data are picked up the respect to actual satellite pointing during roll maneuver of satellite. The schematic figure is shown in Figure .1

The Evaluation Method is followings;
(1) Pick up wind velocity data from satellite observation (Figure 1)
(2) Calculate absolute NRCS using wind speed and incidence angle by the equation 1 at each position picked up at (1). The data obtained this process is same as simulated observation data by EarthCARE/CPR.
(3) Estimate wind speed over the observation area according to be constant wind speed at the area.
(4) Calculate absolute NRCS each points from wind speed.
(5) Compare (simulated) observation data by (2) and estimated data by(4). The difference is the accuracy of this method, which may be different with roll angular velocity.

Figure 1 Schematic Concept



6. THE RESULT

The 263 calibration area (200km by 200km) are selected and the process is done for 4 seasons by 16 days because the returning cycle of AQUA is 16 days. The four angular velocities are chosen, which are 0.35, 0.50, 0.60, and 0.65 degrees per seconds. If there is not available data in 200km by 200km area, the process is not performed. The total data are about 8000, it is depends on roll angular velocity. The result is summarized by cumulative distribution function in Figure 2. The accuracy of the estimation is evaluated by 70% threshold. The table 2 is described summary.

Figure 2 The cumulative distribution function of calibration error by sea surface calibration mode

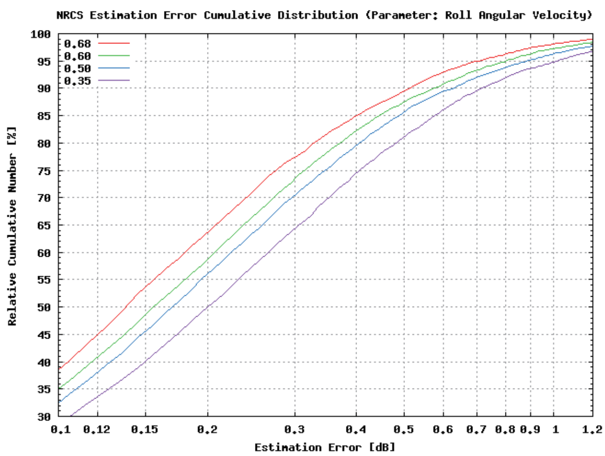


Table 2 The Calibration Accuracy

Velocity	Error	Number
0.68 deg/s	0.27dB	7664
0.60 deg/s	0.29dB	7955
0.50 deg/s	0.35dB	8050
0.35 deg/s	0.36dB	8288

7. CONCLUSION

The evaluation of sea surface calibration accuracy is done by using satellite wind speed data. The data are processed over 8000 scenes and cumulative distribution function of calibration accuracy is obtained. The threshold for calibration accuracy is set to 70%, because all number is expressed one sigma between ESA. All requirement of sensor capability is also expressed one sigma number and it is feasible. It seems the difference between maximum and minimum roll angular velocity is only 0.1dB, but overall external calibration accuracy is required within 1 dB, so it is very important number. The budget of all external calibration accuracy is not shown here, but the feasibility of external calibration accuracy is obtained by this analysis. We will further improve data analysis method in order to obtain better calibration accuracy than now.

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