Data Simulation of Geostationary Space-borne Precipitation Radar Based on APR-2 Data

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Abstract. Due to the importance of some function and performance verification for the future geostationary space-borne precipitation radar (GSPR), a data simulation method based on the second airborne precipitation radar (APR-2) is introduced in this paper. In this method, the low resolution volume of GSPR is divided into finer resolution sub-volumes which are matched with the resolution of the APR-2 data, and the Doppler spectrums of each resolution volume of GSPR are constructed from the Gaussian shape and their intensity, average frequency and spectrum width are decided by the reflectivity and Doppler frequency of APR-2 data. Results indicate that the simulation method is feasible and simulation data can show some characteristics of GSPR echoes.

Introduction

In order to survey strong convective weather timely, such as storms and hurricanes and improve their warning time, NASA is studying Low Earth Orbit (LEO) space-borne precipitation radar, meanwhile, they proposed the instrument concept and related technologies of Geostationary Orbit (GEO) precipitation radar [1]. GSPR (geostationary space-borne precipitation radar) is designed to operate in a geostationary orbit at an altitude of 36,000km, and its working frequency is 35GHz. A 35-m spherical antenna reflector is used with a 28-m effective antenna aperture which contains two pairs of feeds. In each pair, one transmits signal, the other one receives echo. The distance between the T/R feed source is designed to compensate the time delay of long-distance transmission [2]. The two pairs of feeds distribute symmetrically in the rotating arm and slide at a constant speed. When the arm is rotating, the feeds are scanning spirally in 0-4°. As shown in Fig.1(a), the vertical resolution of beam is 250-m and the minimal horizontal one is about 12-km. The diameter of circular disk on earth surface is 5300-km, the scanning period is 1hour, the 3-dB beamwidth is 0.019°. Fig.1(b) shows a schematic diagram of spiral scanning path based on Archimedean model [3].
Analysis of Doppler Spectrum Model

Doppler spectrum of GSPR is weighted power spectrum distribution of scatter radial velocity. The weighting function not only depends on the reflectivity of the scatter, but also depends on the antenna pattern function, the transmitted pulse shape and the response of the receiver to the transmit pulse. For the GSPR, the emphasis should be put on the horizontal resolution of the transverse distribution of reflectivity field \[4,5\]. The formula is shown as follows \[4\]:

\[
P(r, f) = \int_{\phi_{\min}}^{\phi_{\max}} \int_{\theta_{\min}}^{\theta_{\max}} \eta(f, \theta, \phi) W(r, n_r) r \sin \theta d\theta d\phi dr
\]

(1)

Where \(\eta(f, \theta, \phi)\) is the intrinsic Doppler velocity spectrum, Here it is assumed that the power spectrum of each airborne data is consistent with the Gaussian model, \(W(r, n_r)\) is the Weighted function, which contains the antenna pattern function and range weighted function, etc. The formula of this weighted function is shown as follows:

\[
W(r, n_r) = \frac{C \cdot G_a^2(\theta, \phi) \cdot [G_j(r - n_r)]^2}{L(r) \cdot r^4}
\]

(2)

After the discrete-time sampling, the power spectrum of the signal processor output can be expressed as:

\[
P_n(r, f) = \sum_{i=-M}^{M} P(r, f + iPRF)
\]

(3)

However, each complex voltage sampling echo signal is the linear sum of the backscattering echo of the precipitation particles in the radar resolution volume:

\[
S_n = \sum_i V_i \cdot W_{i,n} \cdot e^{-2\pi f R_{n,i}/\lambda}
\]

(4)

Where \(W_{i,n}\) is the discrete value of \(W(r, n_r)\), \(R_{n,i}\) is the distance between the rainfall particles and the radar, \(P_n(r, f)\) is obtained by using M sampling sequence \(S_n\) for DFT transform. Finally, the basic model of the Doppler spectrum of the GSPR is obtained \[4\]:

Figure 1. (a) Typical GSPR parameters. (b) Schematic diagram of spiral scanning path.
\[
P(f) = \frac{1}{M} \left| \sum_i V_i W_i \exp(-2 j 2 \pi R_i / \lambda) \sum_{n=0}^{N-1} \exp(-2 \pi (2v_i + f) T_i n) \right|^2
\]

Data Processing

Because the horizontal resolution of APR-2 is 400-m, vertical resolution is 30-m, and the horizontal resolution of GSPr is 12-km, vertical resolution is 250-m, so that we use 30 data in horizontal direction, 8 data in vertical direction to form one GSPr data. The data processing process will be described in detail below.

Antenna Weights Processing

GSPr is designed to use spherical antenna reflector, the antenna gain function in the far field region is expressed by the following formula:

\[
f^2 \left( \phi - \phi_\theta, \theta - \theta_\phi \right) = \frac{4 \pi^2 D^2}{\lambda^2} \frac{J_1^2(u)}{u^2}
\]

\[
u = \frac{\pi D}{\lambda} \sin \left( \theta - \theta_\phi + \left( \phi - \phi_\theta \right)^2 \right)
\]

Where \( D \) is the diameter of the spherical antenna, \( J_1(u) \) is the first order Bessel function, \( \lambda \) is the wavelength, \( \phi \) is the Pitch angle and \( \theta \) is the azimuth angle. As the GSPr antenna sidelobe requirements of -35dB, a Taylor weighting method is used to suppress antenna sidelobe. In this paper, Fig.2(a) is the result of Taylor weighting. And thirty weight coefficient in the 3-dB beamwidth is used and weighted in power spectrum at each row of APR-2 data block. Finally, the effect of antenna gain is removed by dividing the weighting number.

Range Weighted Processing

Considering the use of pulse compression method in geostationary spaceboren precipitation radar, the simulation also carried out the range weighting [5]. In this paper, the Gauss weighting function is used to deal with the range data as shown in Fig.2(b). eight values are used as the range weighted coefficient and weighted in power spectrum at each column of APR-2 data block. The results also are needed to remove the effect of the weighted gain.

Moving Average Processing

The resolution will be low and the obtained I/Q time series will be uncorrelated if only in accordance with the size of GSPr resolution from APR-2 data block, which will influence the accuracy of velocity estimation [6]. Thus this paper adopts the way of moving average as shown in Fig.2(c). We use ten APR-2 data points as step value in the horizontal direction, three APR-2 data points as step value in the vertical direction.
Figure 2. (a) Antenna pattern of Geostationary precipitation radar. (b) Range weighted function. (c) Schematic diagram of moving average.

**Result and Analysis**

This paper uses the APR-2 data as shown in Fig.3(b), it comes from the second air-borne precipitation radar, and due to the same working frequency with GSPR, this paper use these APR-2 data to simulate the GSPR data. The data processing flow chart is shown in Fig.3(a) [7]. We suppose that the power spectrum of each APR-2 data matches the Gaussian Model. Fig.3(c) is a GSPR data block composed of a 30 * 8 APR-2 data. it is The data in Fig.3(c) is extracted from the APR-2 data. It is weighted in power spectrum at each row of APR-2 data block and removed the influence of the gain of antenna, the same process at each column. Then use DFT algorithm on synthesis spectrum shown in Fig.3(d) to estimate the spectrum parameter such as reflectivity and velocity. We use ten APR-2 data as step value in the horizontal direction, three APR-2 data as step value in the vertical direction to do moving average processing among data block. Results are shown in Fig.3(e).
Figure 3. (a) Flowchart of data processing. (b) APR-2 data. (c) APR-2 data block, Equivalent to a GSPR data. (d) The synthetic spectrum. The green dash line represents the ideal spectrum, the solid blue line represents the ideal spectrum influenced by fluctuation and noise. (e) The reflectivity and velocity of simulated GSPR data.

Summary
The purpose of this paper is using the APR-2 data to simulate the GSPR data, taking the characteristics of GSPR into account, such as resolution ratio, antenna weighting methods, pulse
compression and so on. A Gaussian spectrum shape and range, azimuth weighting are adopted to construct the synthetic spectrum of GSPR. In addition, a moving average method is used to make the I/Q data related and improve the contrast effects between APR-2 data and GSPR data. Results shows that the simulated time echo can be used for the algorithm verification, such as the clutter suppression and spectrum estimation. However, this paper also has some shortages, such as the simulated data only consider the vertical downward condition of the radar beams, data changes caused by scan angle will be taken into consideration in further study.

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References


