Space-borne Precipitation Radar Echo Simulation based on Time Domain Method

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Abstract

Echo simulation plays an important role in verifying the performance of space-borne precipitation radar system. In this paper, a time domain method based on space distribution model of precipitation particles is introduced. In the simulation, the effects of precipitation attenuation, surface clutter and rainfall velocity are also considered. Based on the radar parameters of the geostationary spaceborne precipitation radar, the radar simulation data is generated. In addition, different low side-lobe pulse compression algorithm and antenna sidelobe level are also considered in the simulation to analyze their effects to future radar measurements. Preliminary results has shown that the simulated data can be used to analyze the performance of radar system and its effects to the radar measurements.

Keywords

Echo simulation, space-borne precipitation radar, precipitation cell, pulse compression.

1. Introduction

In order to realize the measurement of global precipitation, developing space-borne precipitation radar becomes an indispensable means. The Space-borne precipitation radar can not only provide the three dimensional structure information of precipitation, but also can obtain precipitation estimation which is independent of land and ocean radiation characteristic [1]. Due to the limitation of funds or experimental conditions, space-borne precipitation radar cannot verify its performance directly, just like ground-based radar and airborne radar, so echo simulation is necessary. The simulation of this paper is based on the parameters of geostationary space-borne precipitation radar (GSPR) which is known as NEXRAD-in space [2]. G The space-borne precipitation radar was designed to work in geostationary orbit at an altitude of 36,000 km and operate at a frequency of 35 GHz. A deployable, 35 m spherical antenna reflector together with two antenna feeds were used to perform spiral scans from nadir to 4 °to cover a 5300-km circular disk on the Earth’s surface. In this paper, some performance of radar system can also be analyzed through echo simulation, such as range side-lobe suppression capability of radar waveform, clutter suppression capability of antenna pattern, and the influence of Doppler shift caused by particle movement.

2. Method

2.1 Spatial Distribution Model

Usually, the radar echo at each range-bin is taken as the total sum of particle scattering in each radar resolution unit, which is determined by radar antenna beamwidth and pulse width. In this paper, the rectangular grid [4] method is used to build the spatial distribution model of precipitation particles for each radar resolution unit. The precipitation space is divided into several precipitation units which are taken as sub scattering cells.

Ignoring the influence of the earth curvature, a three-dimensional coordinate system is established which nadir direction is the Z axis. As shown in Figure 1(b), the spatial region is divided into several precipitation cells according to a certain spatial resolution which contain many precipitation particles. The precipitation cell is regarded as a unit of scattering. It is assumed that the radar reflectivity factor and the falling velocity in each scattering cell are only related to the height of the scattering cell and the size of precipitation particle. If the cell coordinates in the space is known, the falling speed, the antenna gain, path integral attenuation and the echo of this cell will be simulated according the radar system, and then the spatial precipitation echo at each echo cell superposition will be obtained.

According to the spatial coordinate system and its corresponding radar reflectivity factor, the precipitation cell can be described:

$$Cell_i = [x_i, y_i, z_i, Z_i]$$

Where x_i, y_i, z_i is the spatial coordinates of i th precipitation cell and Z_i is the corresponding reflectivity factor in the i th precipitation cell.

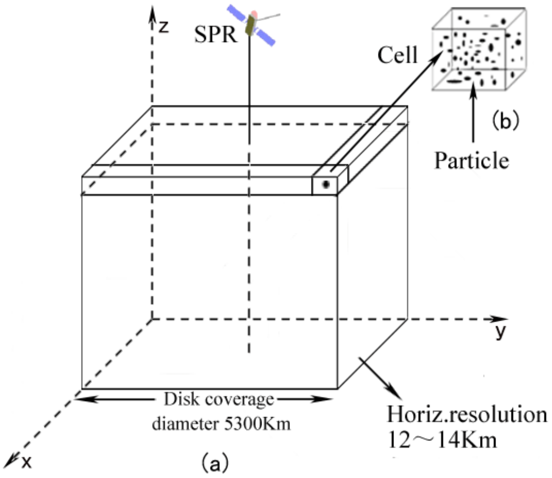

Figure 1.Spatial distribution model of precipitation particles

2.2 Analysis of Radar Echo

The echo from the space-borne precipitation radar is composed of precipitation echo, surface clutter and noisy, produced by particles in different phases [5] likes other echo from conventional meteorological radar. Lot of factors, such as radar system parameters, radar reflectivity, particles movement and path-integrated attenuation, would affect the echo of the space-borne precipitation radar. The radar reflectivity of precipitation is determined by radar reflectivity factor Z, scattering characteristic of precipitation particles and the wavelength of radar. Echo simulation should also consider the phase variation caused by the movement of precipitation particles [6]. The primary factors affecting the movement of precipitation particles are the size of the particles, wind shear and turbulence. The radial velocity of scattering particles in the radar beam is usually different. So there is a Doppler spectrum in the echo data instead of a exact Doppler frequency value. Due to the serious precipitation attenuation in millimeter-wave, so we can’t ignore this effect of attenuation in radar echo simulation. Particles with different phases have different attenuation characteristics to the millimeter-wave. According to the relationship between the attenuation coefficient and reflectivity factors [7],we can describe the attenuation coefficient of particles with different phases by means of radar reflectivity factor.

When the radar antenna beam of the space-borne precipitation radar illustrates the rain area near surface, it will be easily interfered by the surface clutter [8-9].From the perspective of the antenna, the surface clutter is classified into main-lobe clutter and side-lobe clutter. As far as GSPR is concerned, the surface clutter is usually affected by following factors: the spiral antenna scanning and the internal motions of ground clutter unit, which separately lead to the production of Doppler shifts of ground clutter, and its Doppler spectrum extension.

2.3 Radar Signal Model

According to the radar resolution and the precipitation spatial distribution model in the section above, the precipitation space is divided into several resolution cells. The radar cross section of the cell is calculated by the radar reflectivity, and the corresponding antenna gain is obtained from the antenna pattern, then the Doppler frequency shift is calculated according to the falling velocity of the precipitation cell.

Generally, the waveform of narrowband LFM signal is used for pulse compression. According to the radar weather equation [10] and the precipitation particle distribution model, the radar echo signal of the precipitation unit at i points can be expressed as

$$s_r(t) = \Re \cdot u(t-\tau_i)\exp(j2\pi(f_0+f_d)(t-\tau_i))$$

where $\Re$ is the signal amplitude

$$\Re = \left[\frac{G^2\pi^3\theta\phi\tau c|K|^2}{1024(\ln 2)r^2\lambda^2} A_s Z \right]^{\frac{1}{2}}$$

τ_i is the echo delay of the i th precipitation cell and it is determined by the target cell and precipitation radar radial distance and relative velocity; f_d is Doppler frequency shift for the i th precipitation cell. The amplitude of echo signal is determined by the reflectivity factor of the cell, the antenna gain and the path integral attenuation.

3. Result and Analysis

According to the spatial distribution model of precipitation particles, precipitation attenuation, surface clutter and actual reflectivity factor distribution, echo signal is generated based on the observed reflectivity data of APR-2. In this paper, a low side-lobe pulse compression algorithm [11-12] is used in frequency domain echo signal. The detail process of echo simulation is shown in Figure 2. The result is shown in Figure 3. Figure 3(a), (b) separately show the original reflectivity data from APR-2 observation, and the simulation data for GSPR at nadir.

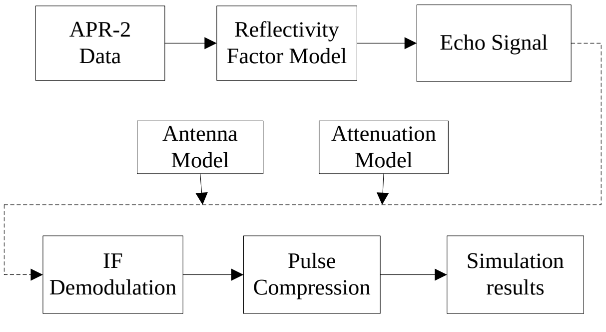

Figure 2. Radar echo simulation process

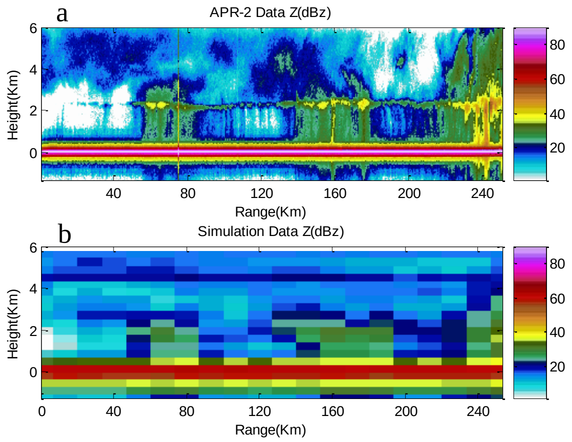

Figure 3. Comparison of APR-2 data and simulation data

In order to clearly compare the original airborne reflectivity echo data and simulated echo data, vertical profile of radial reflectivity data is extracted during the simulation. The results are shown in Figure 4. 4The normalized result in Figure 4(b) is obtained by using low side-lobe pulse compression algorithm and the antenna side-lobe level SLL is -35dB.Compared with the two vertical profile, we can see that the distribution trend of simulation data is consistent with the actual observation data. Due to the strong clutter near the surface, most of the near surface meteorological targets are drowned.

In order to detect weak meteorological targets under the influence of strong ground clutter, a low side-lobe pulse compression algorithm is proposed, which is simultaneously weighted by different windows [13] on transmitter and receiver. But amplitude weighting on transmitter will cause 1~2dB power loss and its main-lobe to be broadened. The results under different weighting window for the side-lobe suppression of echo signal is shown in Figure 5, we can see that the Blackman window can suppress side-lobe in -70dB which has better inhibition effect than Hamming window.

In order to test the antenna side-lobe clutter suppression capability [14-15], radar echoes from antenna side-lobe level (SLL) of -15dB and -35dB are separately simulated. The results are shown in Figure 6. When the antenna side-lobe is -15dB,the echo in the range of 0 ~2Km is flooded by clutter, however when the antenna side-lobe is -35dB,the effect of clutter suppression is improved.

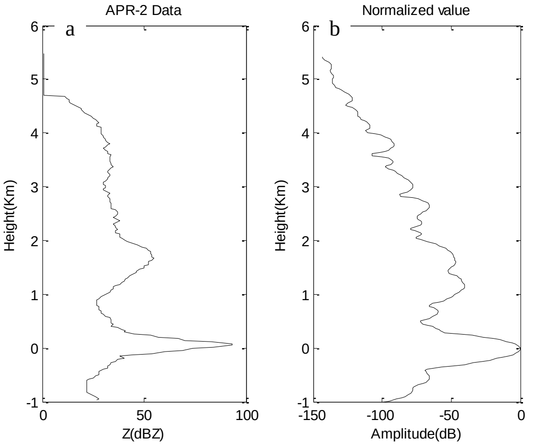

Figure 4.Comparison of one vertical profile of simulation echo data

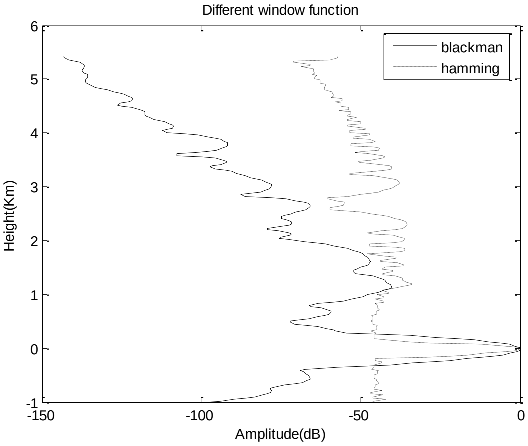

Figure 5.Different window function

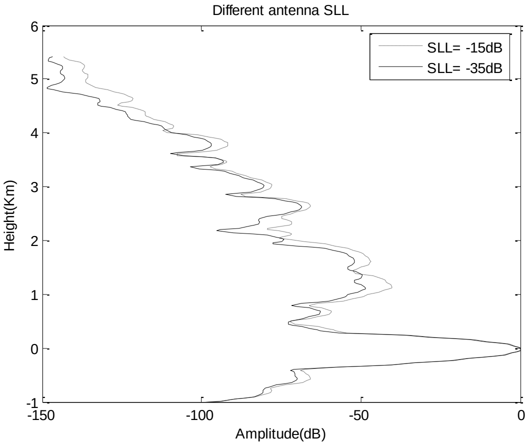

Figure 6.Different antenna SLL

4. Summery

This paper discussed a method of echo simulation in time domain based on space distribution mode the echo simulation results based on the parameters of geostationary space-borne precipitation radar is given . In order to analyze the range side-lobe problem among the pulse compression technique, a low side-lobe pulse compression algorithm by different weighted window function is used to analyze and compare the clutter suppression capability from range side-lobe. At the same time, the suppression capability of clutter under different antenna side-lobe levels is also analyzed. Results show that this radar echo simulation from our method can be used to analyze and test some radar performance for space-borne precipitation radar.

Acknowledgements

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References

[1] Im E, Smith E /, Durden S L, et al. Instrument concept of NEXRAD in space (NIS) - a geostationary radar for hurricane studies[C]// Geoscience and Remote Sensing Symposium, 2003. IGARSS '03. Proceedings. 2003 IEEE International. IEEE, 2003:2146 - 2148.

[2] Im E. Instrument concepts and technologies for future spaceborne atmospheric radars [J]. Proceedings of SPIE - The International Society for Optical Engineering, 2005, 5659:61-72.

[3] Liu L, Duan C, So H C, et al. An investigation of geostationary Doppler weather radar performance based on mean Doppler radial velocity and spectrum width measurements [J]. 2014:710-713.

[4] Richard L. Mitchell. Radar Signal Simulation[M]. Artech House, Dedham, Massachusetts, 1978.

[5] Eastwood Im,Stephen L.Durden. Recent advances in spaceborne precipitation radar measurement techniques and technology[J].

[6] Sreekanth R.Pallikala and Richard K.Moore. Determing Winds Aloft With A Radar Wind Sensor:Accounting for Rain-Drop Fall Speed[J].

[7] V. CHandrasekar, Hiroki-Fukatsu, and K.Mubarak. Global Mapping of Attenuation at Ku-and Ka-Band [J]. IEEE transactions and geoscience and remote sensing, Vol,41, No.10.October 2003.

[8] Tagawa T, Okamoto K. Calculations of Surface Clutter Interference with Precipitation Measurement from Space by 35.5GHz Radar for Global Precipitation Measurement Mission [C] //IEEE. IGARSS 2003. Toulouse: [s. n.], 2003(5):3172-3174.

[9] T. Tagawa, K. Okamoto, H. Hanado, and T. Kozu, Suppression of surface clutter interference with TRMM precipitation radar observation[J], in Proc. IGARSS, 2006(5): 2573–2576.

[10] Rodr ǵuez V. Weather Radar Equation for Numerical Integration [J]. 2015.

[11] Zhu D, Dong X, Lin W. Pulse Compression with Very Low Sidelobes in a Spaceborne Weather Radar[C]// IEEE International Geoscience & Remote Sensing Symposium, IGARSS 2008, July 8-11, 2008, Boston, Massachusetts, USA, Proceedings. 2008:V - 252-V - 255.

[12] Tanner A, Durden S L, Denning R, et al. Pulse compression with very low sidelobes in an airborne rain mapping radar [J]. IEEE Transactions on Geoscience & Remote Sensing, 1994, 32(1):211-213.

[13] Nuttall A H. Some windows with very good sidelobe behavior [J]. IEEE Transactions on Acoustics Speech & Signal Processing, 1981, 29(1):84-91.

[14] Dong X, Yin H, Zhu D, et al. Surface clutter analysis and ranging sidelobe level requirements for spaceborne meteorological radars[C]// IEEE International Geoscience & Remote Sensing Symposium, IGARSS 2007, July 23-28, 2007, Barcelona, Spain, Proceedings. 2007:626 - 629.

[15] Cook C E, Paolillo J. A pulse compression predistortion function for efficient sidelobe reduction in a high-power radar[J]. Proceedings of the IEEE, 1964, 52(4):377-389