論文の内容の要旨

論文題目　Investigation of SAR Imaging Mechanism for Ocean Surface by Time Domain Simulation of Microwave Scattering （マイクロ波散乱の時間領域シミュレーションによる海面 SAR 画像の特性解明に関する研究）

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Sea surface observations by satellites or airplanes equipped with synthetic aperture radar (SAR) are effective methods to obtain global ocean data. However, there are some technical issues in retrieving ocean data from SAR images. First, interpretations between SAR images and moving ocean surface are complicated. If observation targets are moving, the received signals in the azimuth direction are modulated. It is well known that SAR images of oceanic scenes include velocity bunching due to orbital motions of ocean waves. Velocity bunching is considered a nonlinear mechanism in SAR images of the ocean. Therefore SAR has a difficulty in analyzing ocean waves. Simulation techniques for SAR images can help to understand SAR imaging mechanisms and to verify analytical algorithms.

In this paper, SAR image simulation is developed to generate SAR images of ocean scenes. The physical optics approximation is applied to calculate microwave backscattering with its phases. The phase is key a factor of microwave backscattering from the sea surface. The simulation is designed to include microwave backscattering from the ocean surface and modulation due to the moving ocean surface. These are important characteristics of SAR images for ocean surface. In order to simulate the ocean SAR images including modulation caused by moving targets, we need to consider time series of microwave backscattering.

At first, the simulation is conducted in the case of a stationary target to confirm fundamentals of the SAR simulation. The simulation parameters such as sampling rate, phase, target scale, and computational grid scale are determined by the simulation of stationary targets. The SAR raw signals as time series of range and azimuth signals exhibit chirping and Doppler shift. Then compression techniques are applied to the raw signal to obtain fine resolutions.

In the case of a moving target, the time domain simulation obtains time series of microwave backscattering with modulations caused by the moving target. The simulated SAR signals are shifted in the azimuth direction by the velocity of the target. The azimuth shift caused by the moving target is consistent with the theoretical value. The azimuth shift of the ocean waves causes velocity bunching in the SAR images. Therefore, the simulation is applicable for SAR images of moving ocean waves.

In addition, SAR intensities in the range direction are simulated for several ocean wind fields to prove whether the simulation is based on the theory of Bragg scattering, which is dominant mechanism of microwave backscattering from the sea surface. The simulated signals include the phases of backscattered microwaves. Thus it can be based on Bragg scattering. The incident angle dependence is simulated from the wind wave to compare with Bragg scattering theory. As the result, the simulated incident angle dependence is in good agreement with Bragg scattering theory. These results show that the SAR image simulation in time domain is able to generate numerical SAR images of moving ocean surface with regard to motion effects and Bragg scattering.

Next, the SAR images are simulated under different wave directions to validate the SAR imaging mechanism for ocean waves. The range traveling wave and its SAR image have a linear relationship. However, the azimuth traveling wave is not shown in the SAR image.

Furthermore, the azimuth signals from the regular wave traveling to the azimuth direction also exhibit the azimuth shifts due to the orbital motions. From the results of the SAR raw signals, the moving wave and the stationary wave have similar signals. The difference is a shortening in wavelength due to the motion of the platform. It means that the modulations caused by orbital motions are not shown in the SAR raw signals of the moving wave.

The backscattering intensity is weak at the surface where the radial velocity is toward the SAR. This is the reason why velocity bunching caused by the orbital motions is not apparent in the simulated SAR signals. The conventional theory predicts that azimuth waves are strongly influenced by velocity bunching and so azimuth waves become nonlinear in SAR imaging. However, the conventional theory does not include the effect on scattering intensity due to tilt modulation of azimuth waves. On the other hand, the simulation is able to obtain SAR signals with motion effect and scattering intensity.

These simulation results suggest that velocity bunching might not occur in accordance with the conventional theory. It is difficult to evaluate velocity bunching in azimuth wave. Then SAR imaging mechanisms of ocean waves are discussed from the perspective of the local incident angles between the SAR and the ocean waves.

In conclusion, azimuth waves are difficult to observe. However, the reason is different from the theory; the azimuth waves are weakly displayed in SAR images due to small variations in local incident angles, whereas conventional theory implies that azimuth waves are difficult to observe because of nonlinearity caused by velocity bunching. However, it is not enough to evaluate the imaging mechanism with modulations by the ocean surface. The SAR imaging mechanism for ocean waves should be considered using this simulation in terms of scattering intensity and motion effect.

In this paper, we mainly discuss the imaging mechanism of ocean waves in azimuth direction. As a next step, we attempt to simulate SAR images of irregular ocean surfaces. The two-dimensional spectra of the SAR images and the numerical ocean surfaces are shown to discuss sophisticated imaging mechanisms. The conventional theory states that azimuth waves are difficult to analyze because of velocity bunching. In particular, high frequency waves of azimuth direction are shifted randomly due to motions of long waves. The simulation would be helpful to indicate how azimuth waves are displayed in SAR images.

Finally, as an application of the simulation, an algorithm is evaluated using simulated SAR images. The algorithm aims to analyze wave height from SAR images. The algorithm is used in the case of a single wave which is traveling parallel to the range direction. The algorithm is applied to the simulated SAR image. Then the accuracy of the retraced wave height is evaluated with respect to the numerical sea surface.