23rd IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Interactive Presentations - 23rd IAA SYMPOSIUM ON SPACE DEBRIS (IP)

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EXPLORING THE FEASIBILITY OF USING CLOUD PROFILING RADARS FOR SPACE DEBRIS DETERMINATION

Abstract

Space debris encompasses all artificial objects orbiting Earth that are no longer functional. The topic of space situational awareness has been attracting increasing interest, with observations primarily done by ground-based RADAR or optical instruments with varying accuracy estimates. The increasing accumulation of space debris in low Earth orbit (LEO) poses a significant risk to operational satellites and space missions. In this study, we explore the feasibility of using space-based RADARs primarily designed to profile atmosphere and clouds to image centimeter-scale debris.

Space-based Cloud Profiling RADARs (CPRs) use active microwave sensors to detect and measure cloud hydrometeors. Instruments like CPR onboard NASA's CLOUDSAT operate at high frequencies (94 GHz) with a pulse repetition frequency (PRF) of 4300 Hz, an antenna gain of 63 dBi, and a peak power of 32.6 dB, designed to detect hydrometeors in clouds and precipitation.

CPR onboard CLOUDSAT is positioned to observe clouds in the nadir-looking direction. For a 5x5 cm space object at about 10 km from the antenna, the RADAR operating at 94 GHz, pulse repetition frequency (PRF) of 4300 Hz, antenna gain of 63 dBi, and a peak power of 32.6 dB will produce theoretically an estimated back reflected signal of about -49 dB. Using synthetic data and simulations, we show that the signal gain from cm-scale space debris can be comparable to that of the three strong echoes that will be recorded by the RADAR antenna. Furthermore, the CPR, with a half-power beamwidth of 0.108 degree can form an 18.8m 3dB radar footprint at 10 km. Even in a worst-case scenario with the relative velocity between CLOUDSAT and space debris being 10 km/s, the RADAR can theoretically collect multiple synthetic reflections from centimeter-scale debris. This synthetically processed data results in a 9 dB processing gain after applying RADAR imaging techniques, thus improving its imaging capability. Since cloud and precipitation signals originate from altitudes of 10–20 km and space debris reflections occur at higher altitudes, their distinct range characteristics could allow for signal isolation.

This study explores the feasibility of utilizing mm-wave space-based RADAR systems, originally designed for atmospheric profiling, for space debris detection. This approach offers an alternative method for monitoring debris populations in specific orbits near the satellite. The results provide insights into the feasibility and limitations of using millimeter-wave CPR payload datasets for space debris tracking and highlight possible future directions for space-based RADAR debris observation strategies.