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ASSESSING THE ENVIRONMENTAL CONSEQUENCES OF SATELLITE REENTRY: IMPACT ON OZONE LAYER DEPLETION

Abstract

The rapid expansion of satellite constellations has raised concerns about their long-term environmental effects, particularly on Earth's upper atmosphere. According to the United Nations Office for Outer Space Affairs (UNOOSA), 11,330 satellites were in orbit as of June 2023, marking a 37.94% increase since January 2022. Projections by Euroconsult indicate that by 2030, satellite constellations—including Starlink, OneWeb, Kuiper, IRIS^2, and Chinese mega-constellations—could reach 17,000 active satellites.

Most decommissioned satellites, particularly CubeSats with typical operational lifespans of 2 to 5 years, undergo uncontrolled atmospheric reentry, where they burn up, releasing aluminum oxides (Al_2O_3) into the mesosphere and stratosphere.

Current studies estimate that in 2022 alone, satellite reentries injected over 17 metric tons of aluminum oxides into the atmosphere. As mega-constellations proliferate, this number could surpass 360 metric tons

annually. Research in Geophysical Research Letters suggests that the reentry of a typical 250 kg satellite can generate approximately 30 kg of aluminum oxide nanoparticles, which may persist in the atmosphere for decades. These particles act as catalysts for chlorine activation, accelerating ozone depletion and disrupting atmospheric chemistry.

This study aims to quantify the impact of satellite reentry on ozone depletion by analyzing changes in ozone (O_3) concentrations before, during, and after reentry events. It leverages data from the Copernicus Sentinel-5P satellite and ESA reentry analysis tools to establish correlations between reentry frequency, aluminum oxide accumulation, and ozone variation. Machine learning models, including Long Short-Term Memory (LSTM) networks and hybrid deep learning approaches, will be used to analyze trends, identify non-stationary patterns, and improve predictive accuracy. Refining our understanding of reentry-induced atmospheric disruptions will provide insights for sustainable space operations, policy recommendations on satellite disposal practices, and mitigation strategies to minimize long-term atmospheric effects.