Process of Earth's Atmospheric Expansion Caused by Solar Activity and Its effect on the Orbit of CubeSats

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Abstract

In 2024, the solar maximum, a period of extremely high solar activity, was observed. During this period, the Earth's upper atmosphere experienced significant variations due to the increased solar activity which included some of the largest flares and CMEs in recorded history, accompanied by massive geomagnetic storms The upper atmospheric expansion and density fluctuations induced by solar activity, such as the solar EUV radiation variations and geomagnetic disturbances, can significantly affect the orbits of satellites in Low Earth Orbit (LEO). In this study, we investigate the relationship between solar activity and the Earth's atmospheric variations using GPS data from the X-ray astronomy CubeSat "NinjaSat" in LEO. Using a method that compares orbital altitude changes derived from NinjaSat's GPS data with those propagated from TLE (Two-Line Element) data provided by NORAD (North American Aerospace Defense Command), the dynamic effects of Earth's atmosphere is extracted, enabling a high time resolution analysis of solar activity and atmospheric variations.

This study statistically reveals a delay of 30-36 hours for the EUV radiation in the shorter wavelength range (25.6-30.4 nm) and a delay of 48-54 hours for variations in the longer wavelength range (117.5-140.5 nm) at around 500 km altitude during the solar maximum. Additionally, by analyzing orbital altitude changes with the effects of EUV radiation removed, we investigate atmospheric density variations caused by extreme geomagnetic storms associated with intense solar flares and CMEs in May and October 2024. The analysis statistically demonstrates a response delay of 9.5 hours to high-energy proton fluxes caused by CMEs, providing a highly accurate indicator for predicting orbital altitude changes associated with severe geomagnetic storms. Furthermore, correlation analysis with geomagnetic disturbance indices in the polar caps and low-latitude regions suggests the contribution of Joule heating, and differences in response times reveal the timescales of the propagation of heated atmosphere from the polar regions to the low-latitude regions. This study serves as a foundation for future research on the effects of solar EUV radiation and geomagnetic disturbances on satellite orbits, aiming to accurately predict orbital altitude changes based on solar activity and geomagnetic disturbance indices.