SPACE WEATHER EFFECTS ON THE SOUTH ATLANTIC ANOMALY AND THE LOW-EARTH ORBIT SATELLITES

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(南大西洋異常と地球低軌道衛星に対する宇宙天気の影響)

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論 文 内 容 の 要 旨

Thesis Summary

Since the beginning of the last century, humankind is continuously racing toward building, developing, and launching satellites to explore the space, starting from the near-Earth space environment to the most distant celestial objects. It is now well-understood that space is not a vacuum, but it is filled with a plasma, a high-temperature gas that conducts electricity. In particular, highly energetic plasma is trapped by the magnetic field near the Earth, forming the radiation belts (a.k.a. the Van Allen belts). Spacecraft operations in these regions could easily be subjected to harmful situations.

This thesis focuses on the energetic protons in the inner trapped radiation belt. One of the main aspects of the inner radiation belt is the South Atlantic Anomaly (SAA), a region with reduced geomagnetic field intensity. Near the SAA, the inner belt is close to the Earth's surface so that the energetic protons can precipitate inside the anomaly as they do in cavities. Thus, this region imposes an additional dangerous radiation source on the Low-Earth Orbit (LEO) spacecraft missions.

The radiation belts are not stationary, but they behave dynamically in response to variations of the space weather conditions. In this work, the numerical approach was considered by developing test particle simulation codes to compute the particle trajectories. The magnetic field models implemented are the combination of the internal (primary) magnetic field model, IGRF, and the external (disturbed) magnetic field model, the Tsyganenko model series. In addition to the magnetic field, the inductive electric field is included in the simulations by direct numerical integration of the Biot-Savart law. The obtained numerical results were compared with satellite observations.

The thesis is organized as follows: In the first chapter, basic concepts on the South Atlantic Anomaly are explained, such as how it is formed and its anomaly effects. In Chapter 2, the numerical methods used are described, and the definitions of some useful parameters are introduced. The

essential methods are the implementation of the magnetic field models, the electric field models, and the test particle simulation models. Chapter 3 discusses the long-term variations of the SAA's magnetic response to the solar wind dynamic pressure and the Interplanetary Magnetic Field (IMF) for 11 years. We have implemented the Tsyganenko model (T96) to study the variations of the SAA center movement, the SAA area, and the minimum magnetic field inside the SAA. Chapter 4 analyzes the medium-term changes of the SAA's magnetic response to the solar wind dynamic pressure, IMF conditions, the Dst index, and geodipole tilting angle by implementing the Tsyganenko models T96, T01 and TS05. In Chapter 5, we have calculated the proton trajectories in the realistic magnetic field to determine the proton flux inside the SAA. We have also studied the effect of the geodipole tilting angle and the geomagnetic storm effects on the proton flux response inside the anomaly and compared the numerical results with spacecraft observations. Chapter 6 extended our test particle simulation model to cover the main phases of a selected geomagnetic storm using the guiding center approximation model (Tao-Chan-Brizard model) to compute the proton trajectories in the realistic magnetic model. Comparisons are made between the runs with and without the electric field to discuss the roles of the inductive electric field. In Chapter 7, we calculated the radiation environment of the SAA on the LEO spacecraft missions. According to the proton flux obtained from the numerical simulations, we could estimate the absorbed radiation dose rates and the Single Event Upset (SEU) rates.

The main results obtained are as follows: First, the geodipole tilting angle and the Dst index are the most influencing parameters on the magnetic field variations inside the SAA, and the magnetic variations in the SAA could be driven by the magnetic poles with respect to space weather conditions. Second, we have elucidated the basic features of the proton flux anomaly using the test particle simulations. For a small geodipole tilting angle, the proton flux was increased in the SAA. The electric field effect on the inner proton belt is significant, and hence, on the proton flux response in the SAA as well. Third, it is found that the proton flux variations inside the SAA are directly influencing and proportionally changing the radiation environment of a selected LEO spacecraft mission. Thus, the proton flux increase in the SAA led to an increase in the SEU and radiation dose rates.