Development of NICT's Radiation Belt Prediction Model

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ABSTRACT
Dynamic changes of the Earth's Radiation belt are one of the well known but still unsolved issues of solar terrestrial physics. This is also important for the practical point of view because relativistic electron can penetrate into a satellite body and causes deep dielectric charging. This phenomenon is one of the major reasons of satellite anomaly. For prediction of space environment around GEO, we will proceed to develop 1) near real time prediction model of relativistic electron environment, 2) high precision global MHD simulation code in this 5-year term from 2011. As for the prediction model of relativistic electron environment, we plan to develop two types of models. One is a near real time prediction model based on the AR model that is a kind of the parametric analysis methods for the time-series data. The product of this model is for daily operation of geosynchronous satellite. The other is a high time and spatial resolution numerical forecast model based on combination between global MHD simulation code and particle tracing code and others. The product of this model is for post analysis of satellite anomalies. We will introduce an overview and current status of our project.

Keywords: satellite anomalies – radiation belt prediction – space weather

1 INTRODUCTION

"Space weather forecast" is a term for nowcasting and forecasting of the variations of space environment within the Sun-Earth system. National Institute of Information and Communications Technology (NICT) is a unique organization which plays a role of operational space weather forecast in Japan. NICT is a Western Pacific Regional Warning Center (RWC Tokyo) of International Space Environment Service (ISES), which constitute of 13 countries all over the world. NICT is broadcasting daily space weather information not only for domestic users, but also for other RWCs with exchanging observational data and forecasting information. Furthermore, space weather monitoring network around Japanese meridian sector are operated by us for obtaining necessary information for space weather forecast under the national and international collaborations. We are also operating numerical space weather forecast by supercomputer, and studying space weather subject applying informatics technology (Fig. 1.).

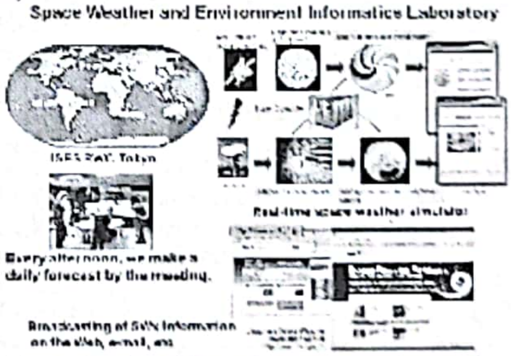

Figure 1. Activities of space weather and environment informatics laboratory in NICT, Japan.

NICT have started the third five-year mid-term plan (2011-2015) since the April of 2011. In this mid-term, we will precede advanced research for space weather forecasting based on the merging among observation, simulation,

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and informatics technologies. The following two major subjects will be studied based on the point of view of social application;

1) Prediction of space environment around GEO: Development of relativistic electron environment prediction model and high-precision global MHD simulation code will be developed for predicting the space environment, especially for the energy range between keV and MeV particles around GEO.

2) Prediction of ionospheric disturbances: Near-real time prediction system for generation and propagation of equatorial plasma bubble and high-precision ionospheric simulation including atomospheric and magnetospheric interactions will be developed for 1 hour ahead of forecasting for ionospheric disturbances.

In this paper, the research about prediction of space environment around GEO, especially for prediction models of relativistic electrons will be introduced. Relationship between space environment and satellite anomalies are introduced in Section 2. The importance of predicting space environment around GEO will be shown in Section 3. Development of radiation belt prediction model will be explained in Section 4.

2 RELATIONSHIP BETWEEN SPACE ENVIRONMENT AND SATELLITE ANOMALY

To understand what kind of disturbances in space environment should be care for mitigating serious risk of satellite operation, several types of the relationship between space environment and satellite anomalies are briefly introduced in this section.

2.1 Surface Charging

Because of the space environment consists the gas of charged particles, which we call plasma, the surface of a satellite can be charged by the balance between the influx of ions and electrons in space environment, and the outflux of secondary electrons and photoelectrons from the surface of the satellite. Discharge of surface charging on a satellite causes satellite anomalies possibly due to injection of several to several tens keV particles during substorm expansion phase.

2.2 Deep Dielectric Charging

Energetic electrons which energy range is more than 100 keV can penetrate into a satellite body. Therefore, theses electrons can charge internal cables, semi-conductor units inside the satellite. This situation can induces deep dielectric charging within the satellite. Discharge of deep dielectric charging in the satellite causes satellite anomalies possibly due to enhancement of relativistic electrons.

2.3 Single Event Upset

High energy particles which have energy range of several tens of MeV~GeV protons, heavy ions due to solar flare (proton event), galactic cosmic ray, etc. can be penetrated into the satellite body. These high energy particles can cause an error within semiconductor devices of a satellite.

2.4 Total Dose Effect

Cumulative long term ionizing damage due to protons and electrons can cause devices can suffer threshold shifts, increased device leakage (& power consumption), timing changes, decreased functionality, etc. This type of effect can be caused by high energy particles due to solar flare (proton event), galactic cosmic ray, etc.

3 IMPORTANCE OF PREDICTING SPACE ENVIRONMENT AROUND GEO

Geostationary Earth Orbit (GEO), which has about 36,000 km altitude, is most practical orbit for telecommunication, meteorological satellite, and so on. More than 300 satellites in GEO are operated in the world. Currently, Japan has more than 20 satellites in GEO. The number of GEO's satellite anomalies per year is more than 60 based on the statistical results. Further, in the case of extreme space weather events, such as severe solar flare, proton event, geomagnetic storm, large number of satellites faced on the anomalies. For example, it is well known that many satellites have experienced satellite anomalies caused by the severe space weather event in Oct.-Nov. 2003, which we call 'Halloween' event. Therefore, for mitigating the risk of satellite/spacecraft anomalies, it is very important to understand the current situation of the space environment, and to predict the future condition of the space environment and its effect to the satellite.

Although there is several kinds of satellite anomalies, satellite charging (including surface charging and deep dielectric charging) is the major (more than 50%) reason (Fig. 2)[1]. As we noticed in the previous section, surface charging / discharging thought to be caused by the injection of several to several tens keV particles related to the substorm. Deep dielectric charging / discharging thought to be caused by the penetration of the MeV electrons from outer radiation belt within the satellite body.

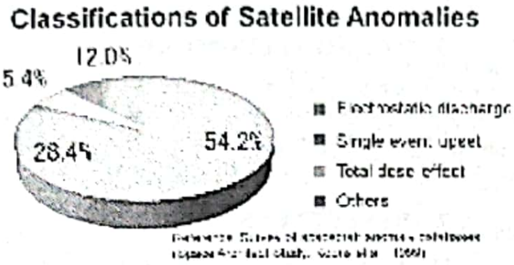

Figure 2. Statistical result of the classifications of satellite anomalies. More than half of the satellite anomalies are caused by electrostatic discharge.

For this reason, predicting substorm and outer radiation belt particles are major subject for the space environment prediction around GEO. Further, it is well known that the particle flux of outer radiation belt tend to increase during the declining phase of the solar cycle due to recurrent type of solar wind streams [2]. Since the declining phase of the current solar cycle (24^{th} solar cycle) seems to be the period after 2014, we need to prepare the practical forecasting model within several years from now on.

4 DEVELOPMENT OF NICT'S RADIATION BELT PREDICTION MODELS

To understand the requirement from the user community about space weather information, we have discussed with the companies of satellite tracking operation. As a result, we have realized that the companies want to know not only for the current condition of space environment, but also for a few days to one week ahead of forecast information of space environment forecast. Also, the detailed space environment information just around the satellite is also very useful for post-data analysis to examine the satellite anomalies.

Based on these user's requirements, we have planned to develop two types of forecasting models. Using these two types of models, we will provide information services to the users in the near future.

<u>Prediction model A</u>: 1-day average flux prediction for a few days ahead as near-real time prediction

<u>Prediction model B</u>: Advanced prediction based on high-time and spatial resolution for post-data analysis

We expect that the prediction model A is useful for the satellite operators. Although spatial and time resolution of information is not high, near real-time quick-look information can be provided from the model A. On the contrary, to diagnose the cause of satellite anomalies, the detailed information about the surface of the satellite itself and surrounding space environment is essential. However, it is quite difficult. To reproduce and diagnose the space environment around the satellite, computer simulation and laboratory experiment is most important tool. These methods can provide detailed information about the space environment. For this purposes, the prediction model B is appropriate because of its high time and spatial resolution. Currently, the real-time calculation is impossible. But real-time calculation is not necessary because of post-data analysis. So detailed space environment information can be provided spending an enough time for calculation.

To develop those two types of prediction models, we will construct the following three elements for developing steps. Each component will be studied and developed step by step. Then, we will reach to the two types of prediction models

<u>First component</u>: Development of prediction filter

This component almost corresponds to the prediction model A. Numerical prediction filter at the satellite location in GEO will be developed based on the multivariate autoregressive method with using time-series of solar wind and relativistic electron data. Since the numbers of satellite points are limited, we can provide forecasting information only at the satellite point. If the satellite particle detector has several energy channels and high spatial resolution of pitch angles, we can develop detailed forecasting model based on these data, and detailed information can be provided for the limited number of satellite point.

<u>Second component</u>: Re-construct the three dimensional distribution of radiation belt particles

The development of this component fills the gap between prediction model A and B. In this component, three dimensional distributions of radiation belt particles in the magnetosphere are estimated from the energy and pitch angle distributions at discrete points in the equatorial region with using particle tracing code.

<u>Third component</u>: Detailed physical model of radiation belt dynamics

This component almost corresponds to the model B. The three dimensional particle flux distribution in the magnetosphere can be estimated from the second component. This distribution is used as an initial condition for the particle tracing code, which will be developed in this component. To include the physical process of acceleration, heating, and loss, such as diffusion process module, and wave-particle interaction module, we will construct a detailed physical model of radiation belt dynamics.

Preliminary version of the first component has been developed already. This model shows very good results of prediction. We are now planning to develop system of relativistic electron flux prediction model and will start test operation as soon as possible.

5 SUMMARY

Electrostatic discharge is one of the major causes of satellite anomalies. These phenomena can be occurred by substorm injection and/or relativistic electron enhancement.

We are developing radiation belt models to produce real-time forecasting information and post-data analysis for analyzing satellite anomalies.

6 ACKNOWLEDGMENT

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