# Geospace Environment Simulator

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In order to evaluate the spacecraft-plasma interactions quantitatively, we have been developing "Geospace Environment Simulator (GES)". A proto model of GES called NuSPACE is an electromagnetic Particle-In-Cell (PIC) simulation code and has been optimized to achieve the high performance with the Earth simulator. To test NuSPACE, we examined the space environment in the vicinity of science satellite "Reimei" launched in 2005. We particularly focused on the Langmuir probes Plasma Current Monitor (CRM) onboard the satellite which measure the current-voltage characteristics for the evaluation of thermal plasma parameters such as density and temperature in the auroral environment. We modified the code to include the Reimei satellite as the internal conductive boundary in the plasma environment. Then we modeled the Langmuir probe on the satellite surface to be able to control the probe potential. Using this model, we performed plasma simulations and obtained the current-voltage characteristics with the probes. In a quiet environment, we succeeded in estimating the electron density and temperature from the current-voltage characteristics obtained with a single Langmuir probe. In the auroral environment which causes large negative charging due to abrupt electron flux, however, we confirmed the single probe does not work correctly and we can estimate the plasma parameter correctly with the double probe.

**Keywords**: geospace, plasma simulation, Particle-In-Cell, spacecraft, Langmuir probe, Science satellite "Reimei"

## 1. Introduction

Geospace is the space surrounding the Earth, where the electromagnetic dynamics of space plasmas plays dominant roles. In the geospace environment many spacecraft such as commercial satellites and space station are now in operation in the geostationary orbit as well as in the low-earth orbit. Since spacecraft surface is basically made of conductor and dielectric materials, it is easily influenced by space plasma. One of the significant spacecraft-plasma interactions to be considered is spacecraft electrostatic charging. Studies on spacecraft charging have been intensively conducted by many researchers since 1960s. Excellent reviews of the progress in the spacecraft charging field have been provided[1),2)]. Spacecraft charging is determined by the net flux of charged particle at the surface including photoelectrons and secondary electrons.

Meanwhile, by controlling the potential of a probe onboard spacecraft we can obtain the relationship between current and voltage. From the current-voltage characteristics, we can estimate the plasma parameters such as electron density and temperature. The probe for this purpose is called the Langmuir probe which conventionally has sphere geometry.

On August 23 in 2005, a small science satellite called "Reimei" was launched for the observation of aurora fine structures and the plasma environment (Fig. 1). On Reimei, two types of Langmuir probe (CRM: plasma current monitor) are installed for the measurement of thermal plasma parameters such as electron density and temperature. CRM

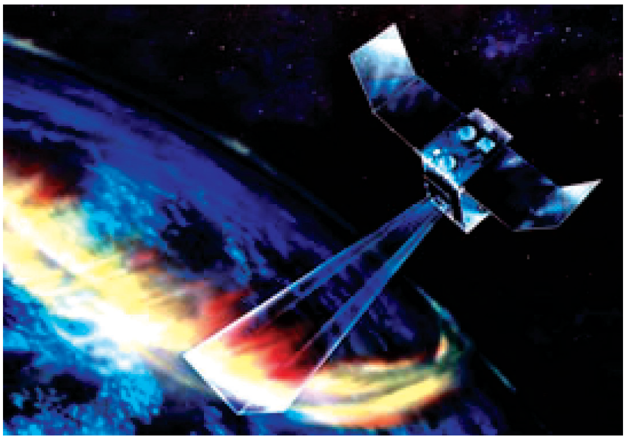

Fig. 1 Reimei satellite (artist impression by JAXA)

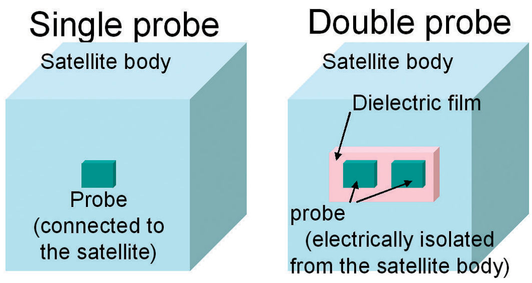


Fig. 2 Single- and double- Langmuir probe.

consisting of single- and double -probes has patch structure, unlike the conventional sphere geometry.

As shown in Fig. 2, a single probe is electrically connected to the satellite body, implying that the probe characteristics are easy to be affected by the satellite charging. On the other hand, a double probe is attached on a dielectric film and electrically isolated from the satellite body. In such a situation, the probe characteristics are less affected by the abrupt change of the plasma environment as well as the spacecraft charging. Although some ground tests for the newly developed probes are conducted, characteristics of CRM in the auroral environment including the effect of satellite geometry have not been obtained.

Meanwhile, to evaluate the spacecraft-plasma interactions quantitatively, we have been developing "Geospace Environment Simulator (GES)"[3]. A proto model of GES called NuSPACE[4] is an electromagnetic Particle-In-Cell (PIC) simulation code and has been optimized to achieve the high performance with the Earth simulator. To test NuSPACE, we started to examine CRM of Reimei in the auroral plasma environment. In the present report, we show some simulation results on the single- and double- probe characteristics and estimation of plasma parameters such as background electron density and temperature.

## 2. A single probe model

We show a three dimensional simulation model for a single probe onboard the Reimei satellite in Fig. 3. The satellite

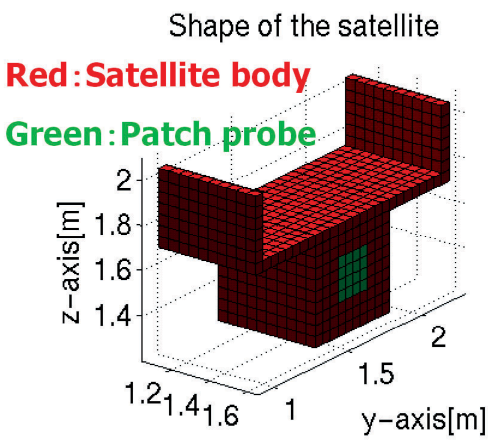


Fig. 3 Simple Reimei model for simulation.

is immersed in the plasma environment corresponding to the ionosphere. For simplicity, we introduced no magnetic field in the simulation model. The plasma density and temperature are $10^{10}m^{-3}$ and 0.5eV, respectively. In the simulation, we swept the probe potential from –5Vto 5V with respect to the satellite body and measured the current which is due to the ion and/or electron impinging on the probe.

In Fig. 4 (a) and (b), we plotted the potential variation without and with the electron beam component corresponding to the aurora current respectively. In both cases, the probe potential is initially 5V below the spacecraft potential and the probe potential was increased up to 5V above the spacecraft potential. When we consider the auroral current as shown in Fig. 4(b), the spacecraft potential becomes negative more than the case without the auroral current and the probe potential cannot reach to the plasma potential. In such a situation, it is difficult to extract the plasma parameters from the obtained current-voltage characteristics. In fact, the estimated electron temperature from Fig. 4(a) is 0.65eV which is close to the temperature value initially given as the simulation parameter which is 0.5eV. However, for the case of Fig. 4(b) the estimated electron temperature from the current-voltage curve is 3.8eV which is far from the initially given temperature. This result implies that the single probe

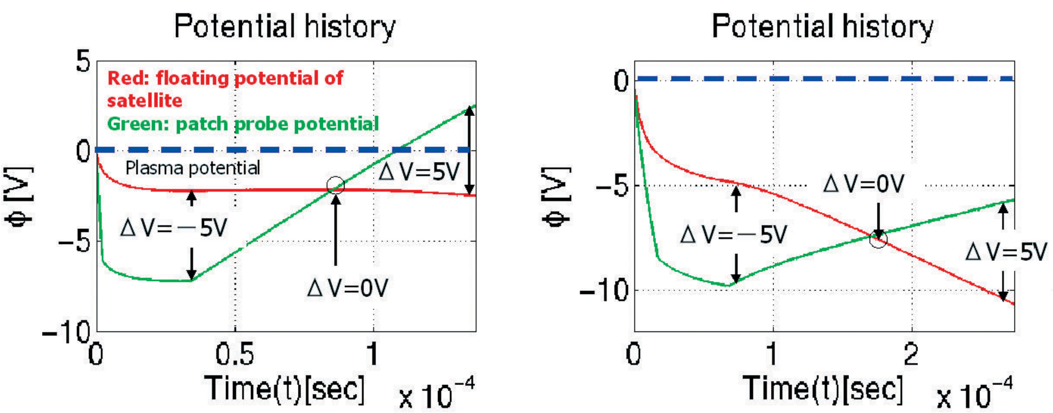


Fig. 4 Potential variation of single patch probe in the plasma environment without electron flux (left), and with electron flux (right).

cannot work correctly to estimate the background plasma parameter under the environment of auroral current.

Next, we examined the basic characteristics of a double probe with the same plasma environment without auroral current. Figure 5 shows the potential variation of two patch probes. We swept the potential difference between the two probes from –5V to 5V. The obtained current-voltage curve is shown in Fig. 6. The electron temperature is estimated from the below equation in which $I_i$, $V_d$, and $I_p$ denote the ion

$$\frac{kT_e}{e} = -\frac{\sum I_i}{A_1\left(\frac{dI_p}{dV_d}\right)_{V_d=0} - A_2\left(\frac{dI_p}{dV_d}\right)_{V_d=V_{sat}}}$$

current, probe potential and probe current, respectively. For the collision-less plasma, $A_1$ and $A_2$ are empirically obtained as 4 and 3.28 respectively. Each term in the equation is obtained from the curve shown in Fig. 6. The estimated electron temperature is 0.512eV and it almost agrees with the initially given plasma parameter.

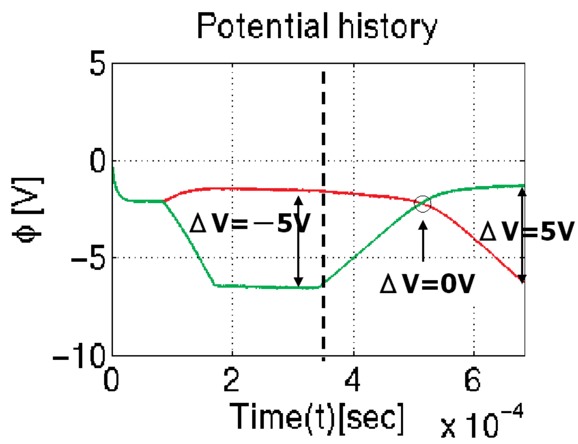


Fig. 5 Potential variation of double probe.

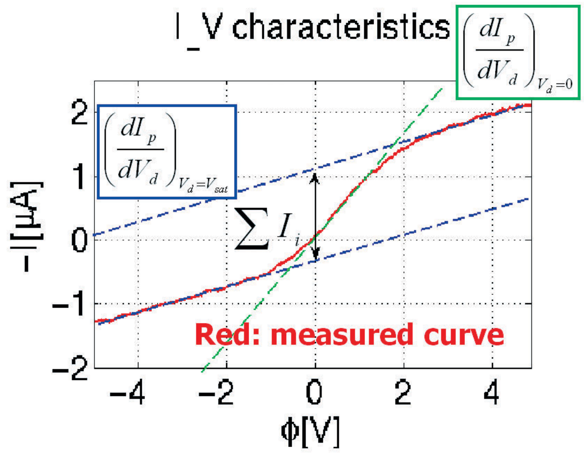


Fig. 6 Current-Voltage curve obtained for the double probe.

## 3. Discussion

We discuss the difference of electron temperature estimated with single- and double probe. Considering the simulation results, the double probe is much suitable for the estimation of electron parameters particularly in the auroral environment. The double probe is electrically isolated from the satellite body and I/C which means the ratio between the incoming current to the patch probes and the electrostatic capacitance is small enough in comparison with that of the satellite body. Since I/C is proportional to the time-derivative of the potential, the temporal variation of the probe potential is much less than that of satellite body which has the larger I/C. In other words, when the satellite encounters abrupt auroral electron flux, the potential variation of the double probe is very little. In such a situation, the double probe is suitable to estimate the background plasma parameters.

## 4. Summary

We have developed a proto model of GES called NuSPACE which is an electromagnetic Particle-In-Cell (PIC) simulation code and has been optimized for the high performance with the Earth simulator. To test NuSPACE, we numerically examined CRM of Reimei in the auroral plasma environment. We modified the code to be able to assume an internal conducting boundary representing Reimei in the three-dimensional space. A Langmuir probe is attached on Reimei which is immersed in a plasma environment corresponding to the ionosphere. By sweeping the probe potential in time, we first tested the current-voltage characteristics of a single Langmuir probe in plasma environment with or without auroral electron flux. In terms of estimate of plasma parameters such as electron temperature, we confirmed that a single probe does not work correctly in the presence of auroral electron flux which causes a large negative charging of Reimei. We next examined the basic characteristics of double probe in the plasma environment with no auroral electron flux. We could confirm that the electron temperature estimated from the current-voltage curve obtained in the simulation quantitatively agrees with the initially given electron temperature. What we stress here is that the estimate with the double probe is much better than that with the single probe. Considering the fact that the double probe is less affected by the potential variation of the satellite body, the double probe is much more suitable for the estimate of the background plasma parameters in the presence of abrupt auroral electron flux. We have been working on the double probe estimate of electron temperature in the plasma environment with auroral electron flux. The obtained results will be utilized to calibrate the Reimei CRM data and the estimate of background electron parameters, which is left as a future work.

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宇宙利用、開発を効率よく進めるためには、非定常・非平衡である宇宙電磁環境を数値シミュレーションによって定量的に評価し、そこでの宇宙機との相互作用を事前に十分理解しておくことが安全面や経済面など様々な観点からみて非常に重要である。今年度は、地球シミュレータ上で最適化された宇宙プラズマ粒子シミュレーションコード(NuSPACE)の検証を具体的な宇宙機環境事例を用いて行った。具体的には、平成17年度に打ち上げられた小型科学衛星「れいめい」搭載の宇宙環境計測用新型ラングミュアプローブ(CRM)により得られた宇宙プラズマ環境パラメータとNuSPACE数値実験データの比較検討を行い、NuSPACEシミュレーションの妥当性の検証を開始した。まずは、NuSPACEに改良を加え、「れいめい」衛星を模擬した内部境界を宇宙プラズマ空間中に設定できるようにした。次に、衛星側面にCRMに相当するラングミュアプローブを設置したモデルを構築し、それを用いてプラズマシミュレーションを行い、得られたラングミュア電流電圧特性曲線から推定される電子温度、密度などのプラズマ環境パラメータの妥当性についてプローブ理論を用いて検証した。次に、オーロラ電流によって急激に帯電を受けた衛星のモデリングおよびプラズマシミュレーションを行った。その結果、衛星筐体が大きく負に帯電する場合は、シングルプローブでは背景プラズマパラメータの推定は困難であり、ダブルプローブ計測が有効であることを示すことができた。NuSPACEに衛星モデリングの機能を付加し、その動作テスト、テストシミュレーションに時間を要したため、まずは、数値シミュレーションの範疇でラングミュアプローブ(シングルプローブ、およびダブルプローブ)特性の取得に専念した。「れいめい」CRMのダブルプローブデータとシミュレーションデータの比較は現在行いつつある。今後、我々のプラズマシミュレーションを観測データの較正に役立てる予定である。

キーワード：プラズマシミュレーション, 粒子法(PIC), 宇宙飛翔体, ラングミュアプローブ, 小型科学衛星「れいめい」