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# Physics-Based Modeling Activity from the Solar Surface to the Earth's Atmosphere Including Magnetosphere and Ionosphere at NICT

**Mamoru Ishii[1], Mitsue Den[1], Hidekatsu Jin[1], Yuki Kubo[1], Yasubumi Kubota[1], Aoi Nakamizo[1], Hiroyuki Shinagawa[1], Daikou Shiota[1,2], Takashi Tanaka[1,3], Chihiro Tao[1], Shinichi Watari[1] and Tatsuhiro Yokoyama[1]**

[1]National Institute of Information and Communications Technology,
4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
email: den@nict.go.jp

[2]Nagoya University,
Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8601, Japan
[3]Kyushu University,
744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

**Abstract.** We present the development of physics-based models of solar-terrestrial regions from the solar surface to the Earth's atmosphere at NICT. Our models consist of three regions: (1) the solar surface and solar wind, (2) the Earth's magnetosphere-ionosphere, and (3) a model of the whole atmosphere from the troposphere to the ionosphere, called the Ground to Topside Model of Atmosphere and Ionosphere for Aeronomy (GAIA). We also have a solar wind and CME model, Space-weather-forecast-Usable System Anchored by Numerical Operations and Observations (SUSANOO). Furthermore, we have developed a high-resolution plasma bubble model. The coupling of these models is a future work.

**Keywords.** Space weather, MHD, methods: numerical, (Sun:) solar wind, solar-terrestrial relations

## 1. Introduction

Space weather is the electromagnetic condition in the near-Earth space which affects human social activities, such as radio telecommunications, broadcast, satellite positioning, power grid and aviation. The importance of space weather information is increasing in our society with a high ICT use. It is necessary to observe space weather with space- and ground-based instruments to monitor the present conditions. In addition, it is also important to develop and use models and simulation codes for space weather forecasting. The ultimate goal should be to establish a space weather forecast system with theoretical models using data assimilation; however, there are some difficulties in achieving this at present. The area we need to observe is very large and the observation points are few. There are still some important but unknown processes in space weather phenomena. Given this situation, it is meaningful to develop empirical models. For a long time, NICT has been developing both empirical and theoretical models of the sun, solar wind, magnetosphere and ionosphere. They have been used for research on the electromagnetic processes in space weather. Our physics-based models cover the solar surface to the Earth's atmosphere. The models for the ambient solar wind and the magnetosphere were developed using the same MHD simulation code called the REProduce Plasma Universe

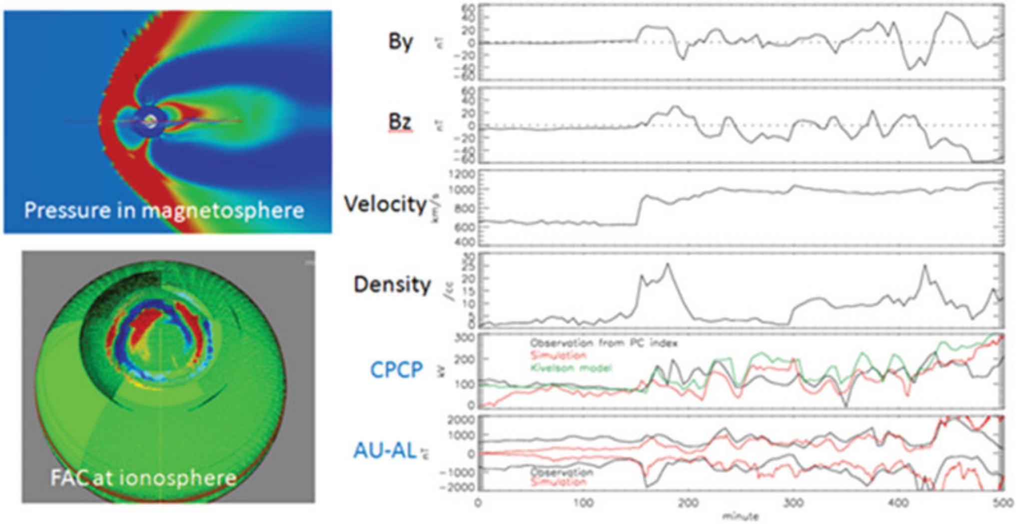


**Figure 1.** Simulation results of the Bastille Day event

(REPPU) code. (Den *et al.* 2015; Nakamizo *et al.* 2009; Moriguchi *et al.* 2008) One of the features of the REPPU code is that there is no singular point in the unstructured grid system, which makes it possible to simulate the global solar wind structure from about 1 solar radius to 1AU and to perform calculation with the uniform accuracy over not only the magnetosphere but also the ionosphere for the case of a strong solar wind such as Bastille event (Kubota *et al.* 2017). GAIA consists of atmosphere, ionosphere, and electrodynamics models, which are coupled with each other (Jin *et al.* 2011). The atmosphere model covers the whole region from the ground to the exobase and treats a full set of physical processes. The ionosphere model solves equations of mass, momentum, and energy for major ion species and electrons. The electrodynamics model treats the closure of global ionospheric currents induced by the neutral wind dynamo.

As REPPU for the solar version (Den *et al.* 2015) and SUSANOO (Shiota & Kataoka, 2016) are described in other papers (see Den *et al.*'s manuscript and Shiota *et al.*'s manuscript), we present information of the REPPU code for the magnetosphere and GAIA with a high-resolution plasma bubble model.

## 2. Magnetosphere

The numerical global MHD model developed by Tanaka (1994) self-consistently solves the SW-M-I coupling process. To achieve high resolution and accurately capture discontinuities, the MHD calculation employs a finite volume total variation diminishing (TVD) scheme with an unstructured triangular grid system, which was described by Moriguchi *et al.* (2008) and Nakamizo *et al.* (2009). The numbers of triangular grid points are 7682 in the horizontal direction and 240 in the radial direction. The outer and inner boundaries of the simulation are set at 200 and 2.6 Re, respectively.

Figure 1 shows simulation results of Bastille Day event (Kubota *et al.* 2017). The left panels are snapshots of the pressure distribution in the magnetosphere (upper) and the field-aligned current (FAC) in the ionosphere (lower panel). The right panels show the solar wind parameters (magnetic fields of By and Bz components, velocity, and density), the CPCP and the AE index. The horizontal axis (minute) is defined as the number of minutes starting from 12:00 UT on 15 July 2000. The red line indicates simulation

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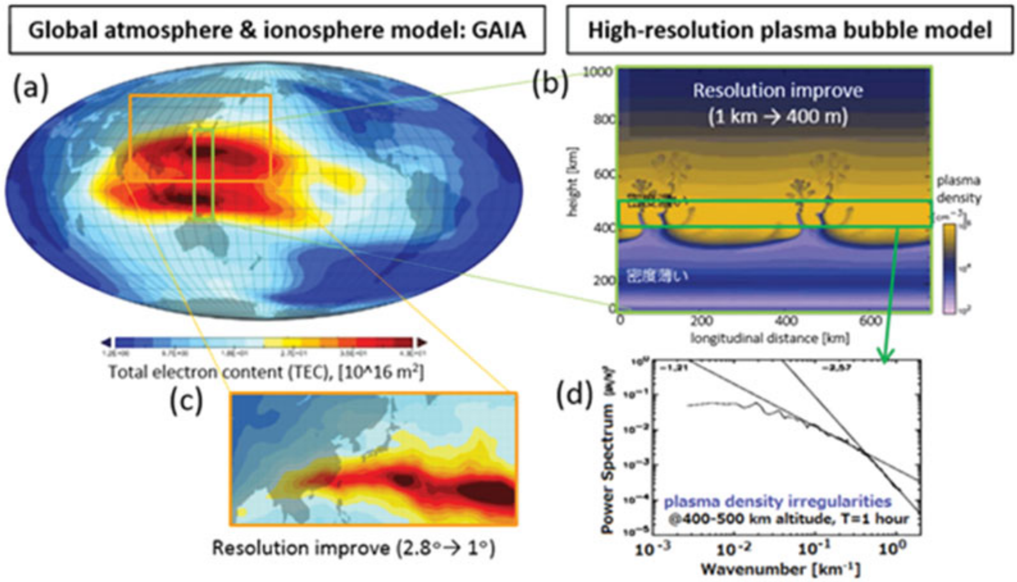


**Figure 2.** Simulation results using GAIA and high-resolution plasma bubble model

**Table 1.** Simulation methods of GAIA and Plasma bubble model.

| | **GAIA (ionosphere)** | **Plasma bubble model** |
|---|---|---|
| Region | global | north-south 20 deg, east-west 3-5 deg |
| Resolution | 2.5(lon.) × 1(lat.) deg, 1-2.8 deg (GCM) | 0.4 - 1 km |
| Method | ion chemistry implicity & momentum balance combined with GCM | CIP (constrained interpolation profile) scheme |
| Referenes | e.g., Jin *et al.* 2011;Shinagawa 2009 | e.g., Yokoyama *et al.* 2014 |

results, and the black line indicates observation values. Our simulation results of the CPCP and the AE index are consistent with the observation.

## 3. GAIA and plasma bubble model

Ionospheric disturbances affect radio propagation and communications, and cause significant errors in satellite positioning. Ionosphere modeling is one of the approaches to investigate and predict ionospheric disturbances. We have been developing two types of ionospheric model: global and local. The global model is the Ground-to-Topside Model of Atmosphere and Ionosphere for Aeronomy (GAIA), which solves the physical and chemical processes of the whole atmosphere from the troposphere to the exosphere under the interaction with the ionosphere (Jin *et al.* 2011) (Figure 2(a)). The local model is a high-resolution local model used to study the behavior and characteristics of the equatorial plasma bubble (e.g., Yokoyama *et al.* 2014) (Figure 2(b)). We have improved the spatial resolution of both the GAIA and bubble models. The high-resolution version of GAIA captures the ionosphere distribution with a horizontal scale of a few hundred kilometers (Figure 2(c)). The high-resolution plasma bubble model reproduces the ionospheric plasma structure with a scale of less than 1 km, showing the spectral breaking feature seen in previous observations (Figure 2(d)).

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