Real-time magnetosphere simulator for space weather using REProduce Plasma Universe code

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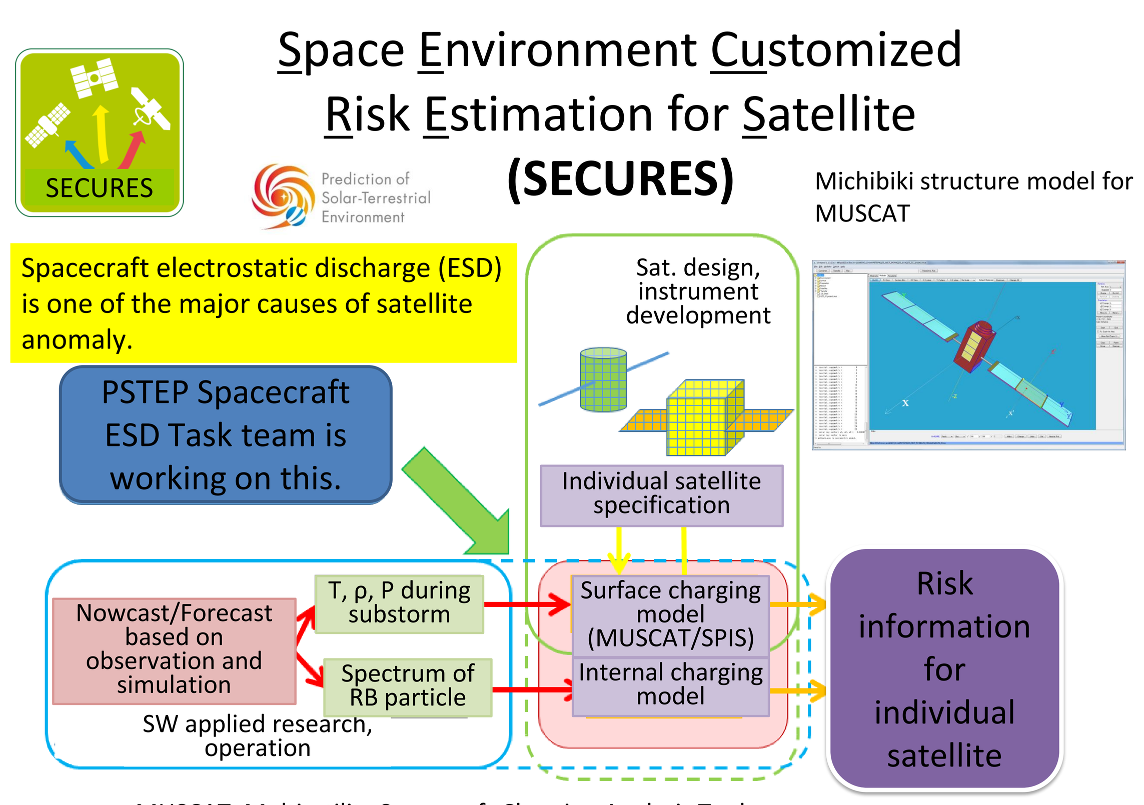
1. Abstract

Surface charging of artificial satellite is one of risks caused by dynamical variations of space environment. It occurs when a satellite exposes high energy electrons around 10 keV created by plasma injection accompanied with substorm. Therefore we want to predict timing and electron energy of plasma injection using magnetosphere-ionosphere coupling global MHD simulation. Now we are developing a real-time numerical simulator for space weather forecast using magnetosphere-ionosphere coupling global MHD simulation called REPPU (REProduce Plasma Universe) code. The feature of the simulation code is highly robust to extreme solar wind parameters because the unstructured grid system has no singular point and is able to calculate in the uniform accuracy over the whole region. We use the real-time solar wind data formatted in the GSM coordinate system observed by DSCOVR spacecraft. Magnetic-dipole axis is fixed to z-direction in our simulation. Therefore daily variation of magnetic-dipole axis is not reproduced. Instead, we convert the input direction of the solar wind velocity and magnetic field into that which tilts including daily variation of magnetic dipole axis in x-z plane. In the method the solar wind structure is not exact. However we can relatively reproduce the magnetosphere response including daily variation of the magnetic-dipole axis against solar wind. The resolution is 7682 grids in the horizontal direction and 240 grids in the radial direction.

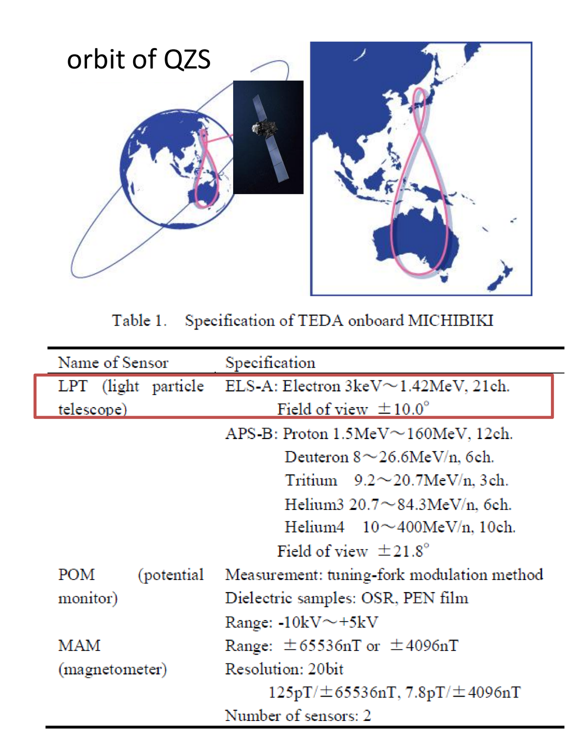
In this presentation, we compare the simulation results with the CPCP, AE index, and plasma variations observed by geostationary orbit satellites. Density and temperature of plasma injection derived from MHD simulation tends to estimate larger and smaller values than observation respectively because the MHD simulation does not include kinetic heating effects. We have to interpret MHD simulation results for prediction of electron density and temperature. We will discuss how to interpret electron density and temperature between observation and MHD simulation.

2. Introduction

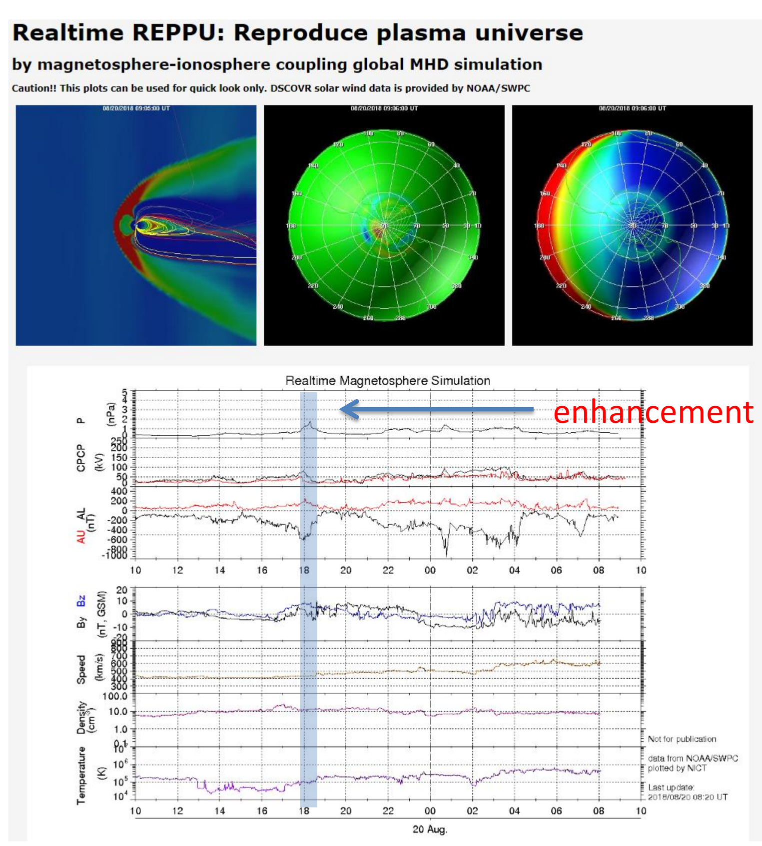
2.1 Risk estimation of surface charging

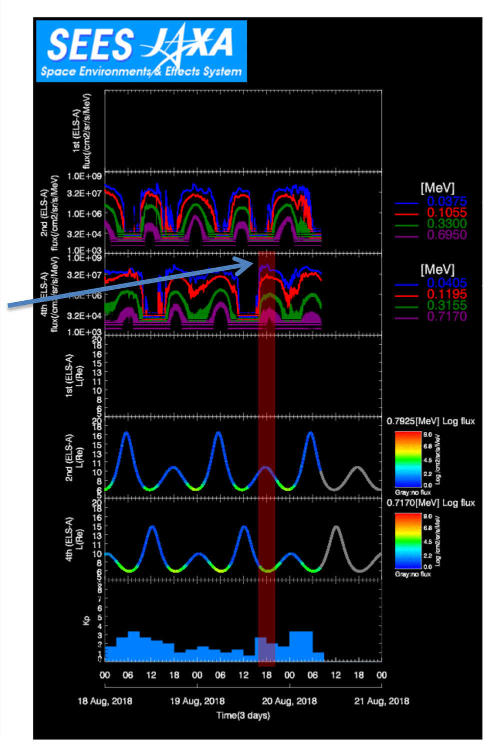


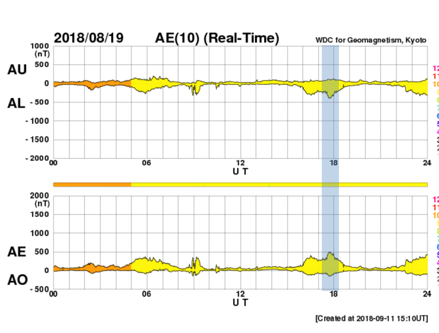
MUSCAT: Multi-utility Spacecraft Charging Analysis Tool



2.2 Real-time magnetosphere simulator





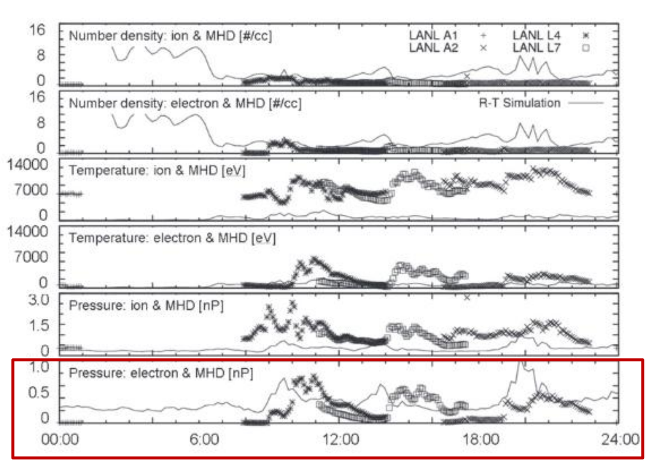


Input: real-time solar wind observed by DSCOVR

We predict plasma injection one hour before.

2.3 Purpose of this study

- Plasma parameters (P, T, ρ) calculated from MHD simulation is not the same as real plasma parameters.
- However, previous study by Nakamura [2012] suggest that there are some relationship between plasma parameters from particle observations and those from global MHD simulation.
- Plasma parameters from observations and those from global MHD simulation are compared to examine empirical relationship between observation and global MHD simulation.



[Nakamura, 2012]

Comparison between plasma parameters from LANL satellites and those from global MHD simulation

3. Model description of MHD simulation

Boundary condition of MHD simulation (M-I coupling)

$\sigma = \sigma_{EUV} + k_2\sigma_{Diff}(P,\rho) + k_3\sigma_J(J_\parallel)$, Conductivity

$\nabla\cdot\sigma\nabla\Phi = (\mathrm{rot}\mathbf{B}_1\cdot\mathbf{n}_b) = J_\parallel$, To solve electric potential

$\mathbf{m} - (\mathbf{m}\cdot\mathbf{n}_b)\mathbf{n}_b = -\rho\nabla\Phi \times \mathbf{B}/B^2$, To derive drift velocity

Conductivity model (mho)

・EUV

$\Sigma_P = \Sigma_H = k_1 * \cos(SZA)$

・Diffuse aurora

$\Sigma_P = k_2 * \mathrm{sqrt}(P * \mathrm{sqrt}(T))$

$\Sigma_H = 3.5 * \Sigma_P$

・Discrete aurora (upward current)

$\Sigma_P = k_3 * J$

$\Sigma_H = 3.5 * \Sigma_P$

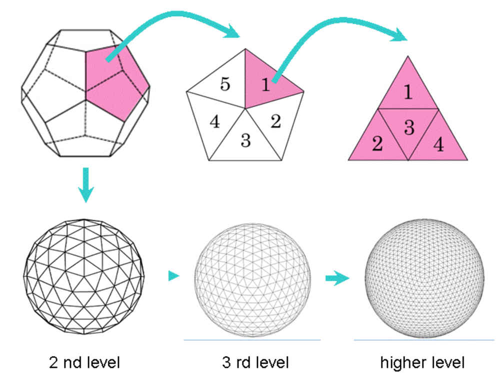
・Resolution:

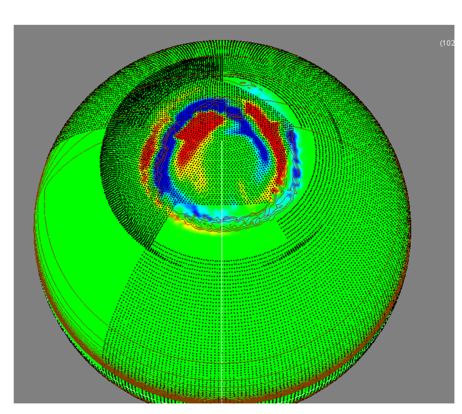
radial direction : 240 grids

horizontal direction :7682 (87.6^2)

triangular grids (5th level)

・Inner boundary: 3 Re





FAC at ionosphere

4. Simulation setup

We simulated 12 surface charging events of LANL satellite between February and April, 2006.

- **Solar wind**

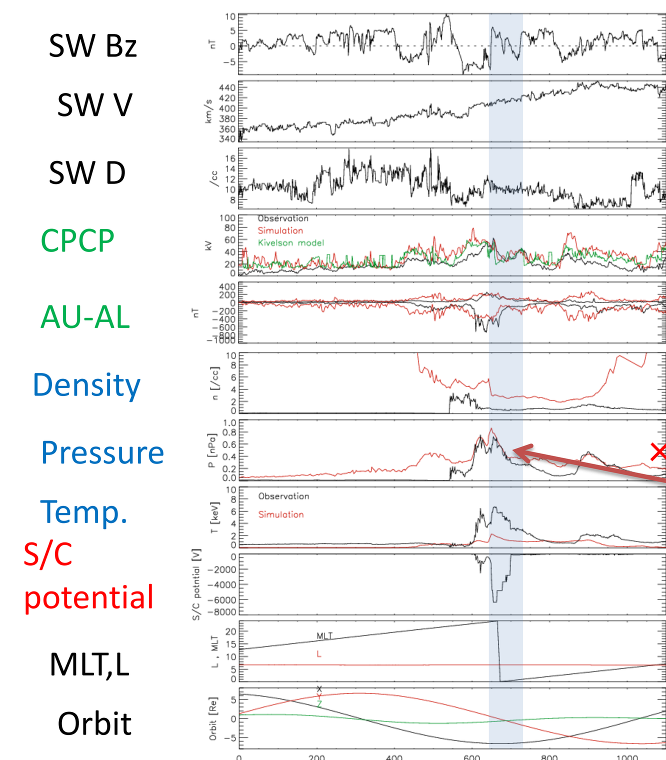
We used the OMNI solar wind data formatted in the GSM coordinate system.

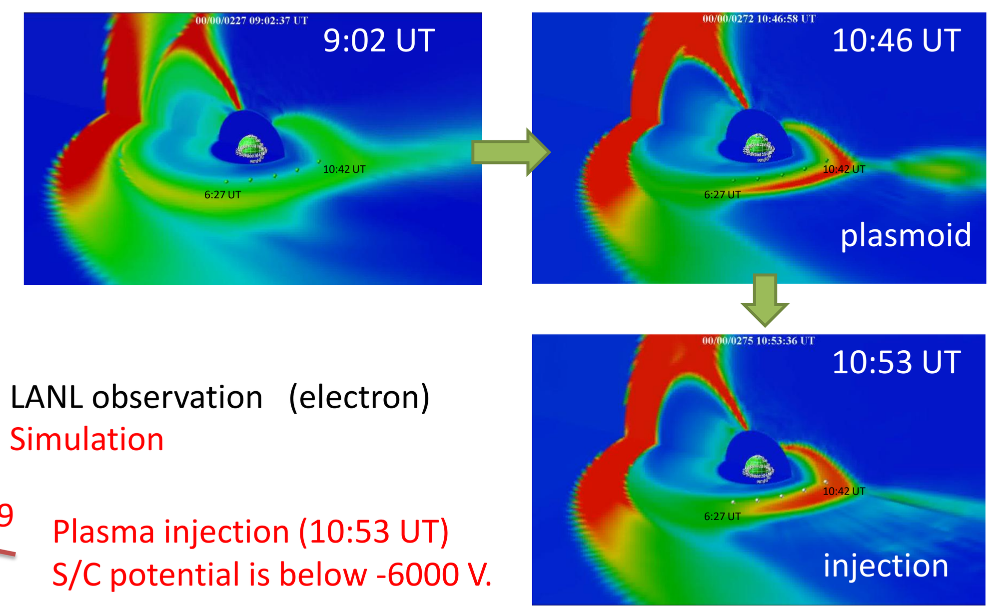
- **Time variation of dipole axis**

The dipole axis is fixed in Z-axis direction of simulation. Therefore time variation of dipole axis is not reproduced. Instead, we transform the input direction of the solar wind into that which tilts including time variation of dipole axis in X-Z plane.

5. Comparison of LANL electron observation with MHD simulation

5.1 2006/2/15 event





LANL observation (electron)

Simulation

Plasma injection (10:53 UT)

S/C potential is below -6000 V.

Electron pressure variation is consistent with MHD simulation.

However,

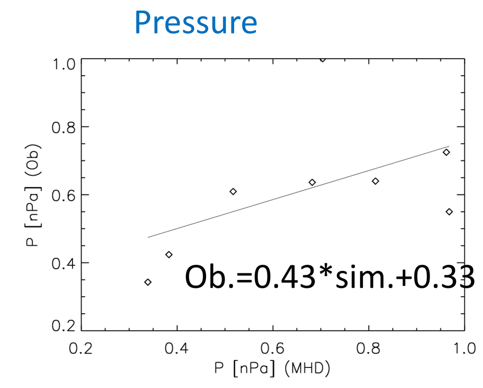
Electron temperature is higher than MHD simulation.

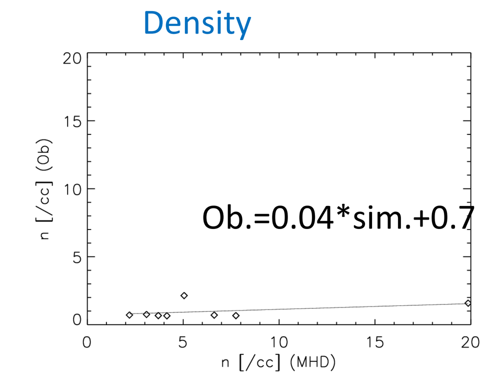
Electron density is lower then MHD simulation.

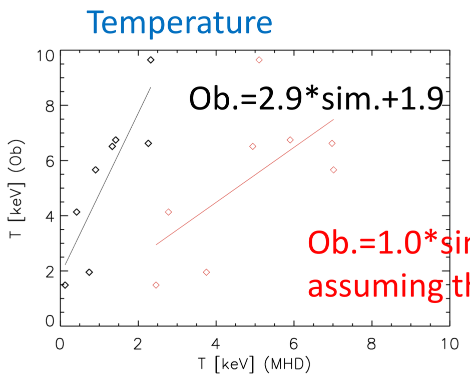
5.2 Comparison of plasma injection between observation and MHD simulation

Peak value of plasma injection : Observation (electron) versus Simulation

8 events in 12 events: The difference of timing is less than 30 minutes.



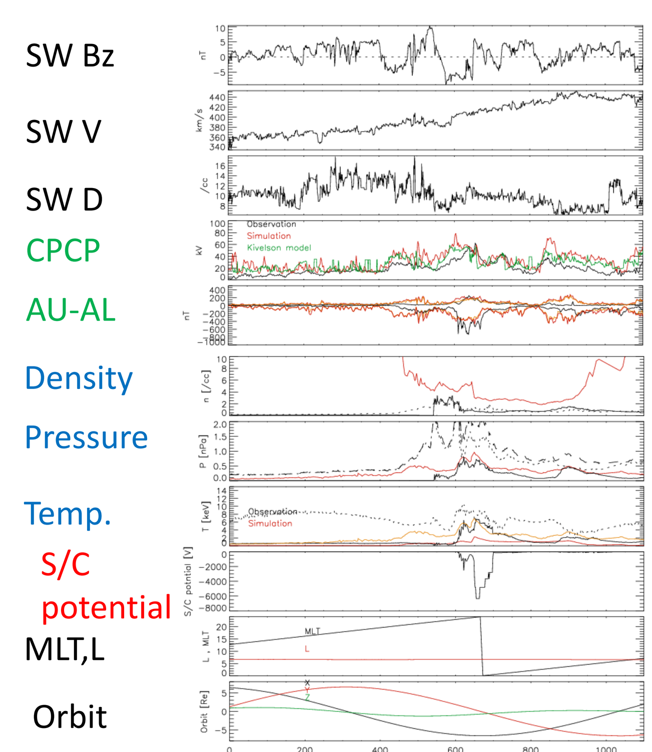




Observed electron density is almost 1/cc.

We derive temperature from pressure in simulation assuming that density is 1 /cc.

5.3 Comparison of time variations between observation and MHD simulation

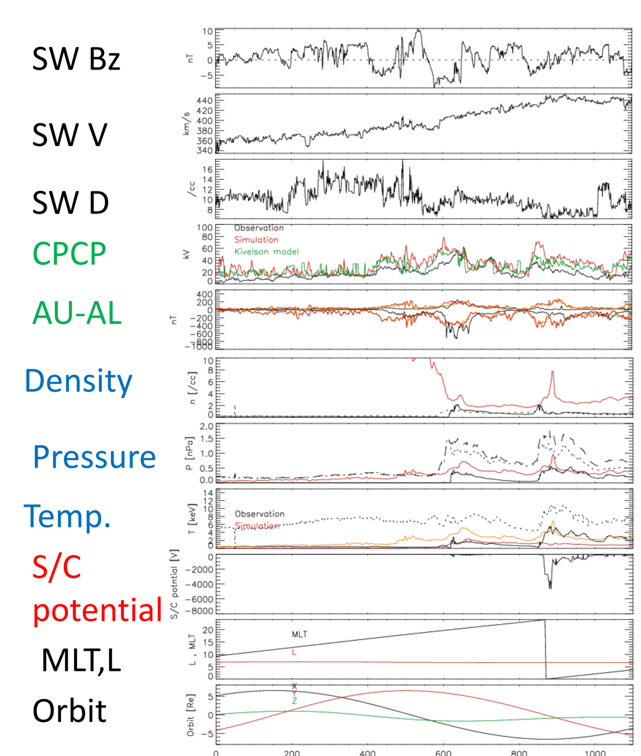


2006/2/15

Correlation coefficients

Pressure : 0.80

Temperature :0.75 (density is 1/cc)

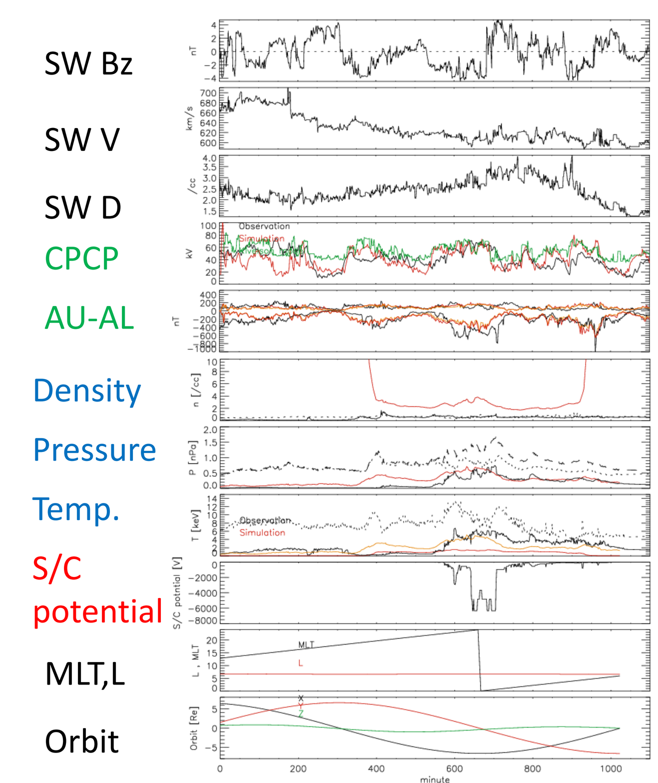


2006/2/15

Correlation coefficients

Pressure : 0.74

Temperature :0.63 (density is 1/cc)

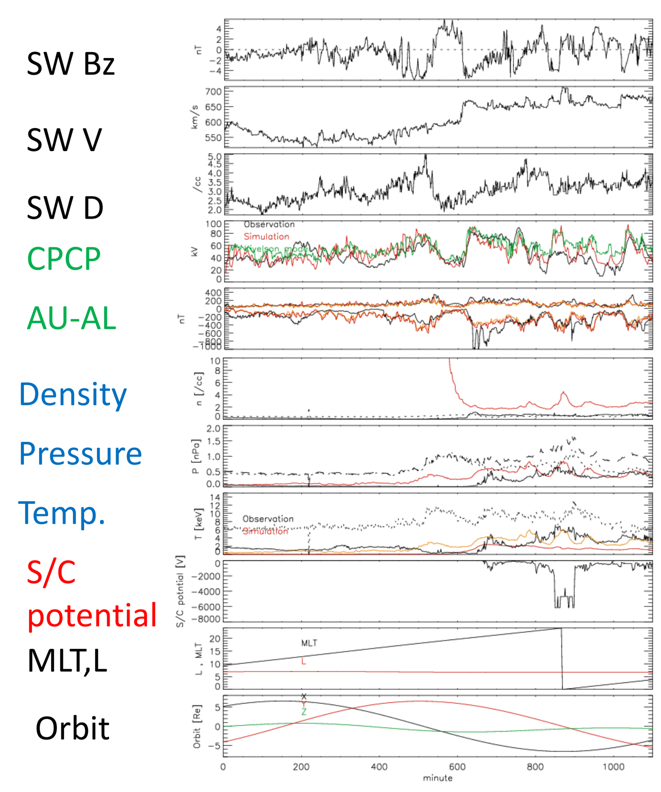


2006/2/22

Correlation coefficients

Pressure : 0.76

Temperature :0.65 (density is 1/cc)



2006/2/21

Correlation coefficients

Pressure : 0.77

Temperature :0.63 (density is 1/cc)

Observed electron temperature variations are consistent with the temperature derived from pressure in simulation assuming that density is 1/cc.

6. Summary

・We developed a real-time numerical simulator (test edition) for space weather forecast using REPPU (REProduce Plasma Universe) code. We can compare the simulation results with the CPCP, AE index, and plasma injection related to satellites charging in real-time.

・The observed electron pressure variation are consistent with the pressure variation obtained from global MHD simulation. The electron density and temperature need to be proceed for establishing the empirical relationship between observation and simulation. The observed electron density of injection is almost around 1 [/cc]. Using the assumption that density is 1 /cc, we can reproduce electron temperature variation from global MHD simulation.