Quantitative modeling of the ring current using ENA data assimilation

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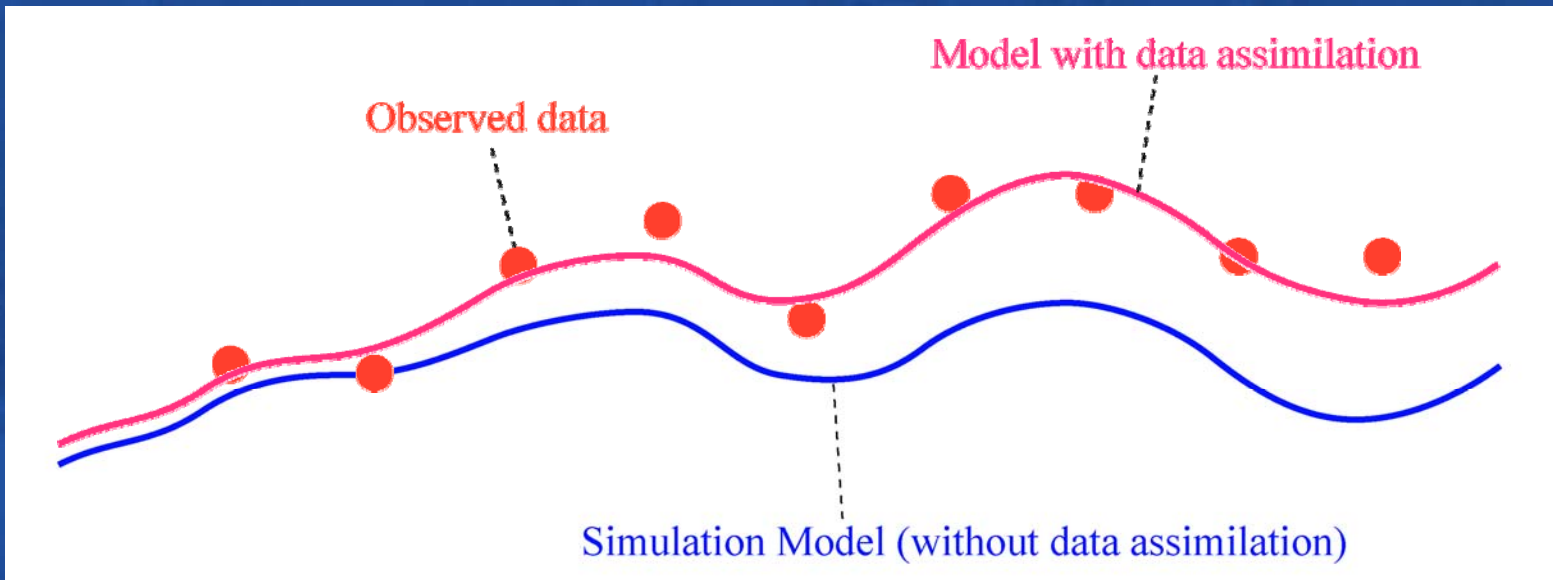
What is data assimilation?

- Data assimilation is a technique to incorporate observed data into a numerical simulation model.



Data assimilation aims at

- (Obtaining a realistic initial condition for prediction with high accuracy,)
- Improving unknown parameters and boundary conditions in the simulation model,
- Obtaining a credible estimate of the evolution of the system.

Overview of this data assimilation framework

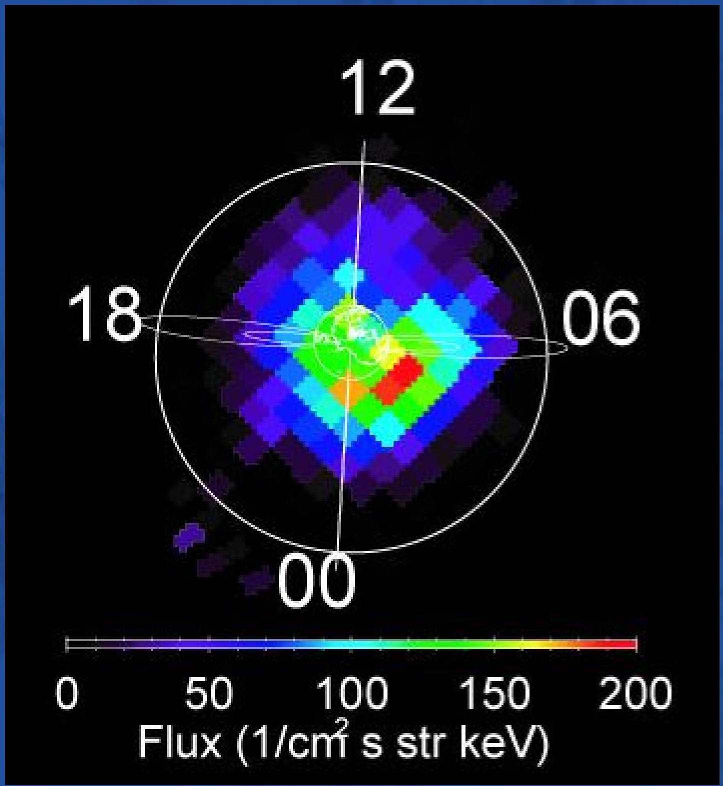
Data: Energetic neutral atom (ENA)
(from IMAGE/HENA)

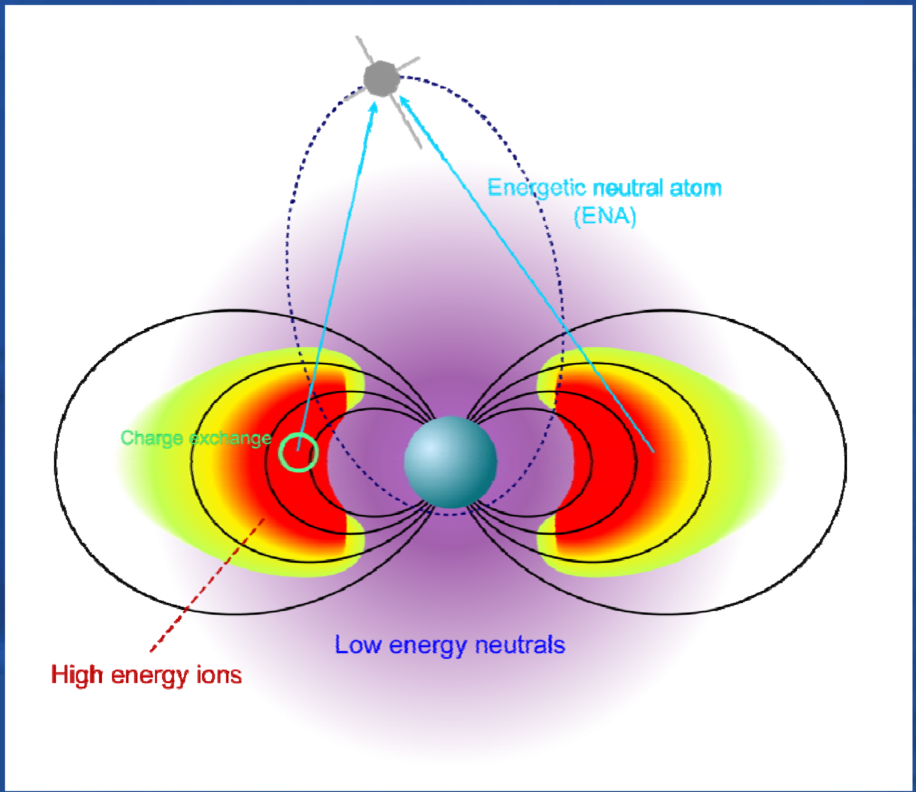
Model: CRCM (Comprehensive Ring Current Model)
[Fok *et al*., 2001]

Purpose: To obtain a credible global model
of ring current evolution by improving
unknown parameters

ENA data from the IMAGE satellite

- The IMAGE satellite provides a global image of ENA (Energetic neutral atom) .
- The resolution is 6 degree by 6 degree.



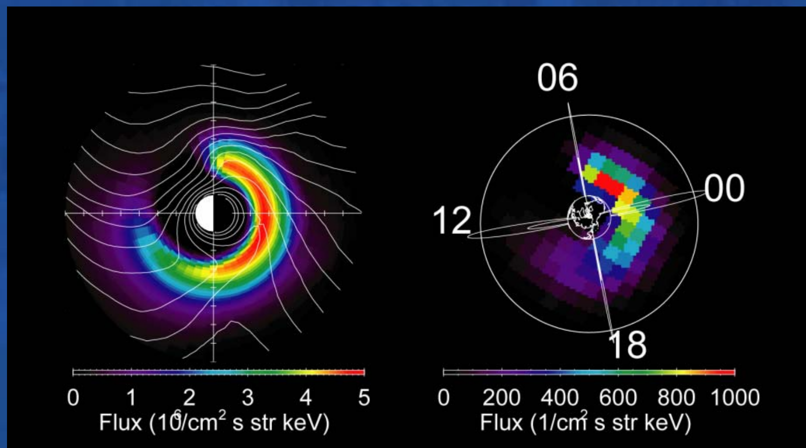


CRCM (Comprehensive Ring Current Model)

- This solves the Boltzmann equation averaged on magnetospheric magnetic field lines.

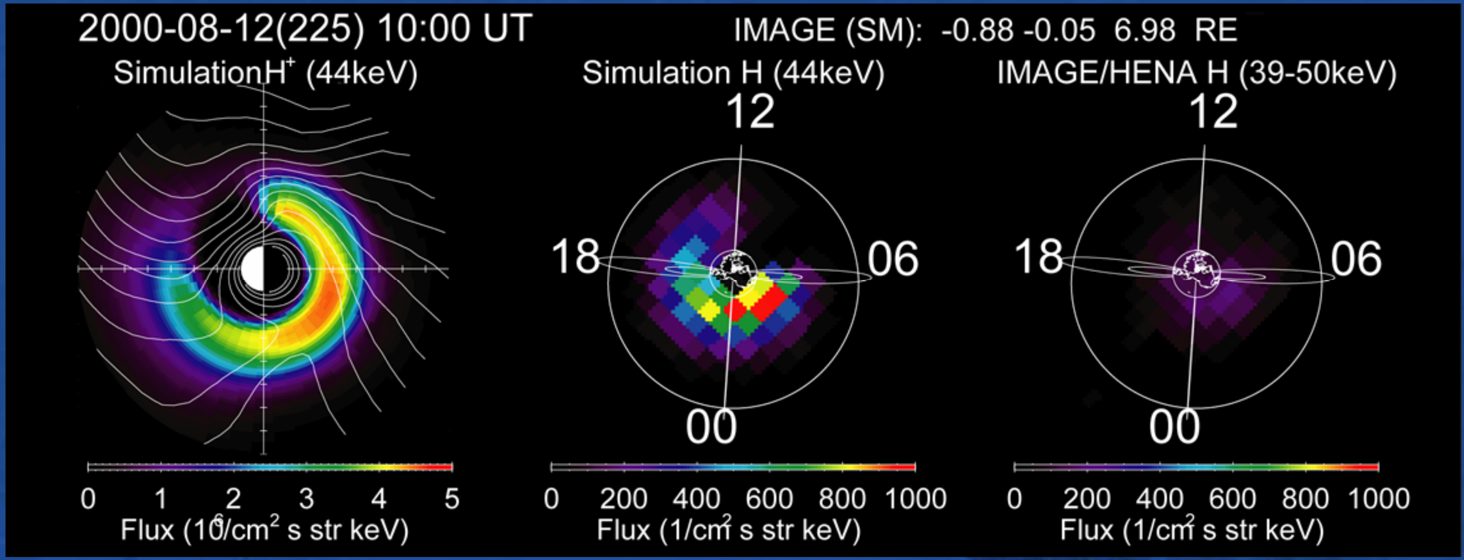
$$\frac{\partial \bar{f}}{\partial t} + \langle \dot{l}_{\mathrm{is}} \rangle \frac{\partial \bar{f}}{\partial l_{\mathrm{is}}} + \langle \dot{\phi}_{\mathrm{is}} \rangle \frac{\partial \bar{f}}{\partial \phi_{\mathrm{is}}} = -v\sigma \langle n \rangle \bar{f} - \left(\frac{\bar{f}}{0.5\tau_b} \right)_{\mathrm{losscone}}$$

- This is a 2-dimensional model. (Phase space density f is 4-dimensional.)
- This model, which calculates pitch angle distribution of f, allows us to estimate ENA flux observed by IMAGE.



Comparison between simulation and observation

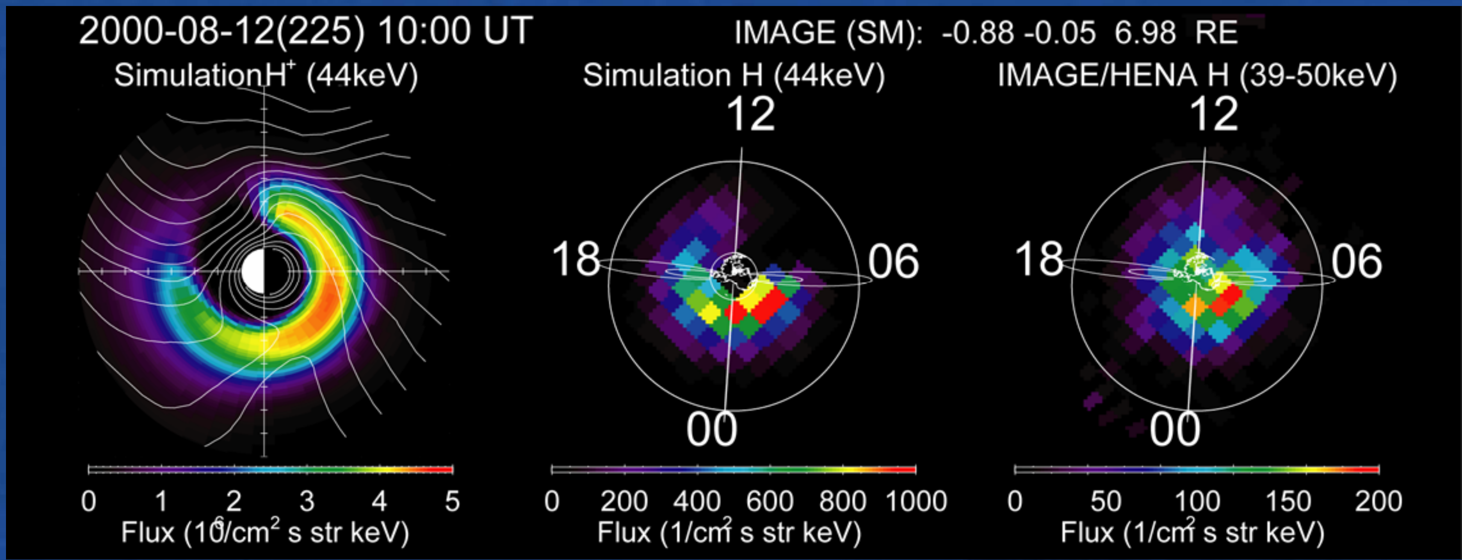
- The simulation result overestimates the observed ENA flux.



Simulation result　　　　Observation

Comparison between simulation and observation

- If the color scale is adjusted, we can obtain the good appearance.



Simulation result

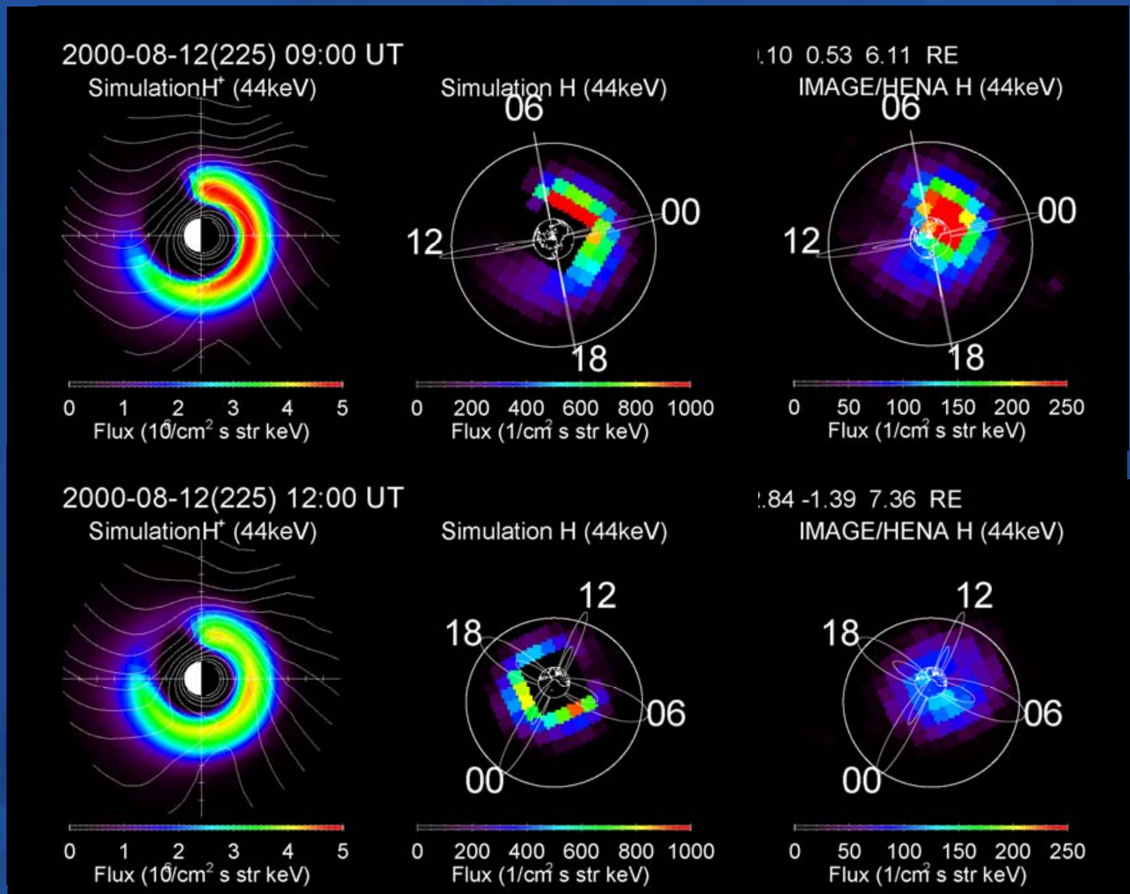
Observation

Comparison between simulation and observation

- But even if the color scale is adjusted at a particular time, the temporal change is not necessarily explained.

0900 UT
(12 Aug. 2000)

1200 UT
(12 Aug. 2000)



Result of Assimilation Observation

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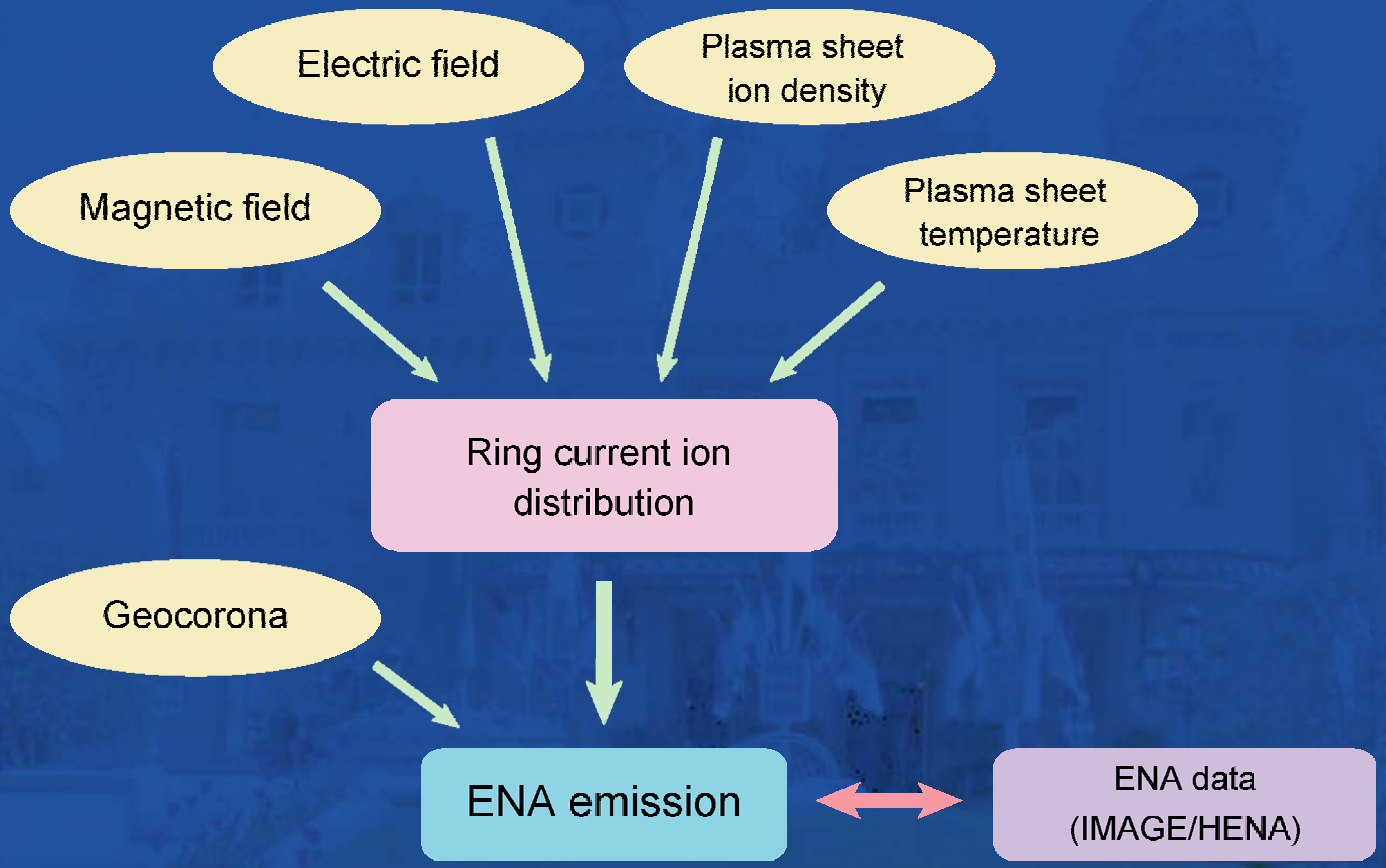
Ring current modeling



Ring current modeling

- The original CRCM
  - Magnetic field ... A model by Tsyganenko and Stern (1996)
  - Electric field structure

    ... Calculated with the RCM (Rice Convection Model)
  - Ion density and temperature at the outer boundary (L=10)

    ... Given by an empirical model of plasmasheet ion density
    (Ebihara and Ejiri [2000])
  - Neutral density around the Earth

    (for the estimation of the ENA emission)
    - Hydrogen ... A model by Hodges (1994)
    - Oxygen ... NRLMSISE-00

Strategy of the present data assimilation

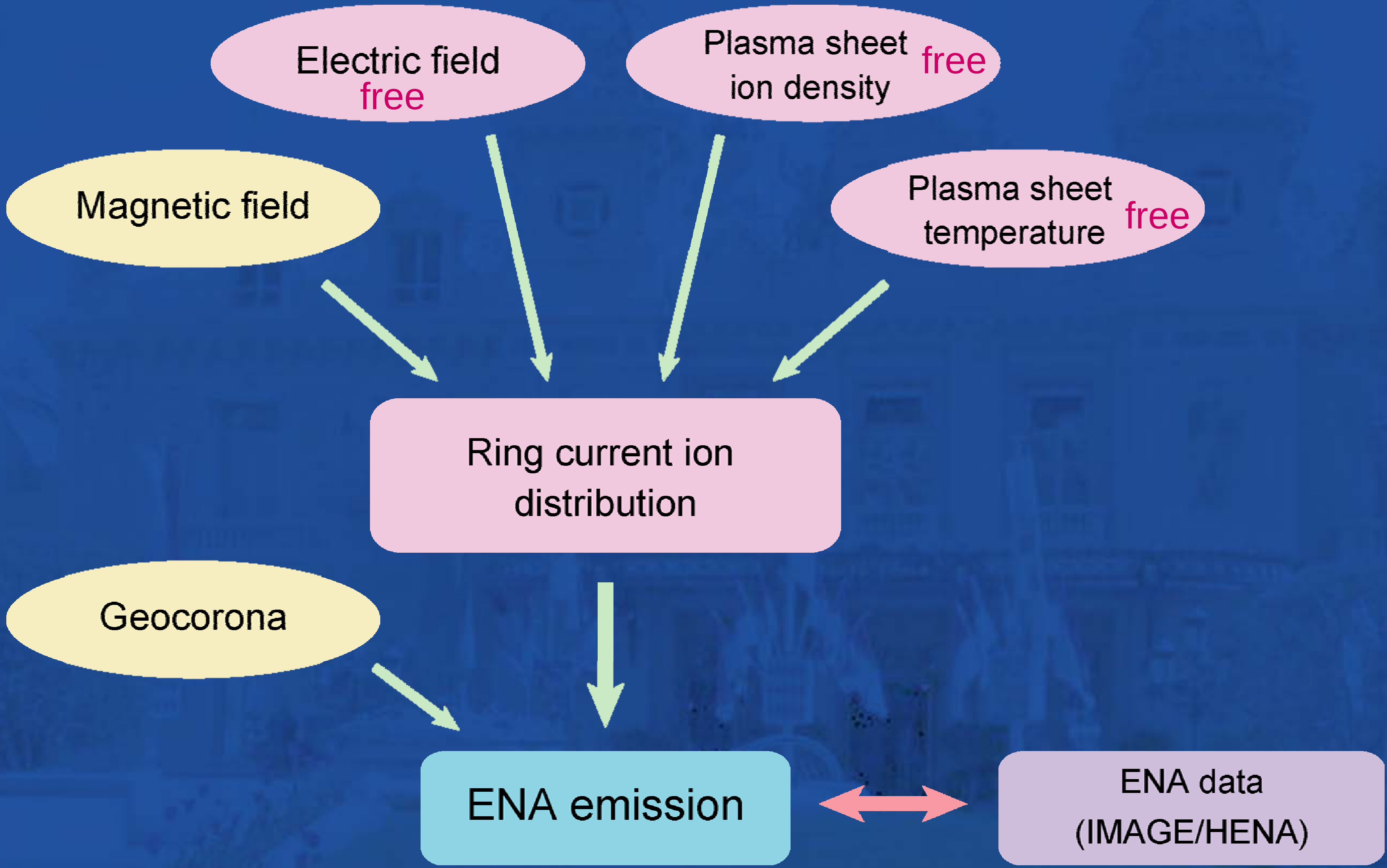
- For the data assimilation
  - Magnetic field ... A model by Tsyganenko and Stern (1996)
  - Electric field structure

    ... Unknown (estimated through the assimilation)
  - Ion density at the outer boundary (L=10)

    ... Unknown
  - Neutral density around the Earth

    (for the estimation of the ENA emission)
    - Hydrogen ... A model by Hodges (1994)
    - Oxygen ... NRLMSISE-00
- The ENA data from IMAGE/HENA are incorporated into the model.

Strategy of the present data assimilation



Strategy of the present data assimilation

- The magnetospheric electric potential at the equatorial plane is given as:

$$\Phi = \Phi_0 \left[\left(\frac{r}{R}\right)^2 \sin\phi + \sum_{i=0}^{3}\sum_{j=1}^{3} J_i\left(\xi_{ij}\frac{r}{R}\right)(a_{ij}\cos i\phi + b_{ij}\sin i\phi) \right]$$

$$\xi_{ij}\text{: the positive roots of } J(\xi_{ij}) = 0 \quad (0 < \xi_{i1} < \xi_{i2} \ldots)$$

  - Here R=10 R_E, according that the outer boundary of the simulation domain is set at L=10.

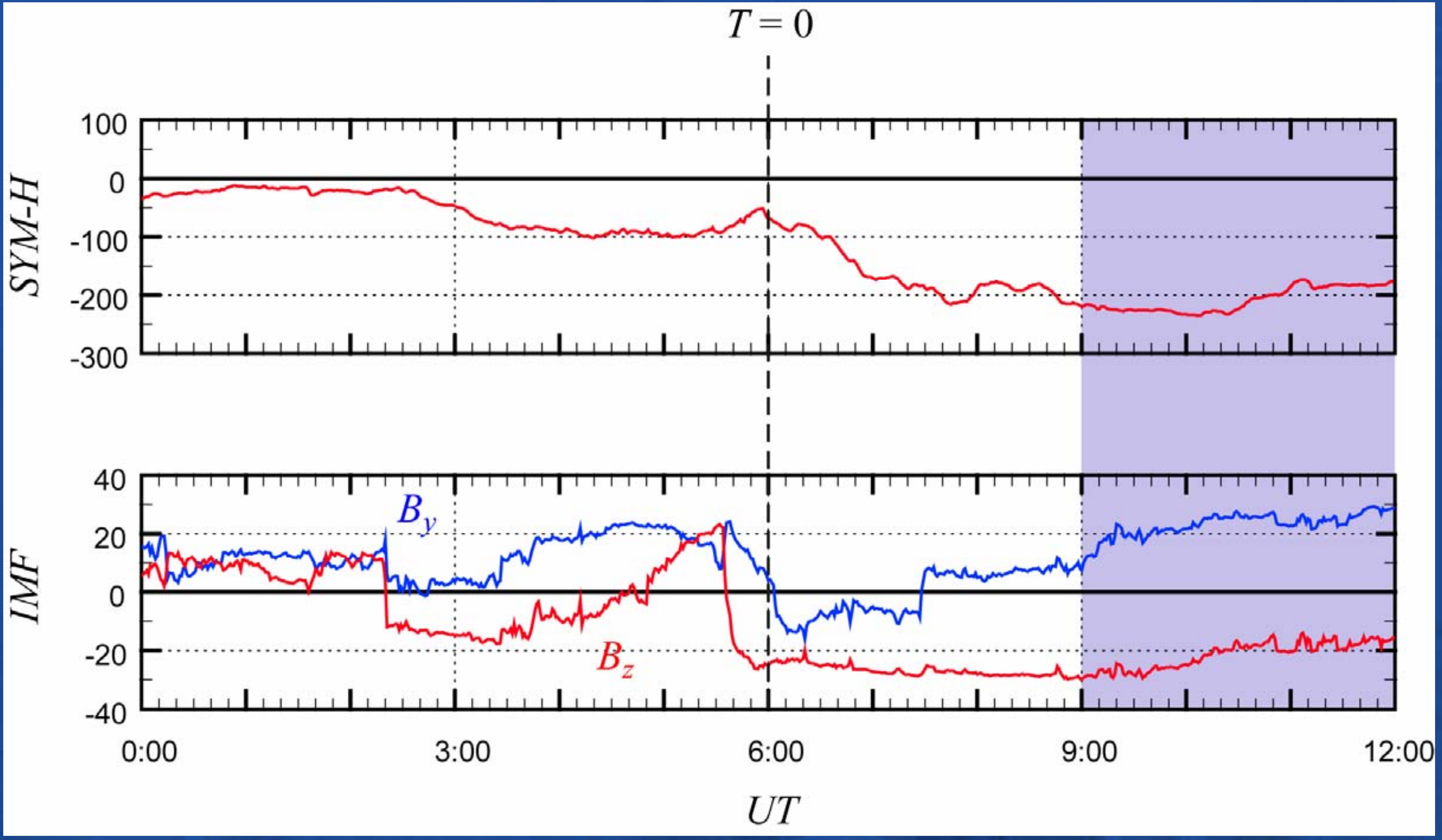
    (In this context, electric potential at L=10 becomes sinusoidal peaked at the dawn.)

  - The optimal values of the parameters Φ_0, a_{ij}, and b_{ij} are sought through data assimilation.

Strategy of the present data assimilation

- Ion density and temperature at the outer boundary are assumed to be independent of local time.
- 12-min averages of ENA data from 2 energy channels (16 – 27 keV and 39 – 50 keV) are assimilated every 12 minutes.
- An algorithm based on the particle filter is used.

Magnetic storm on Aug. 12, 2000



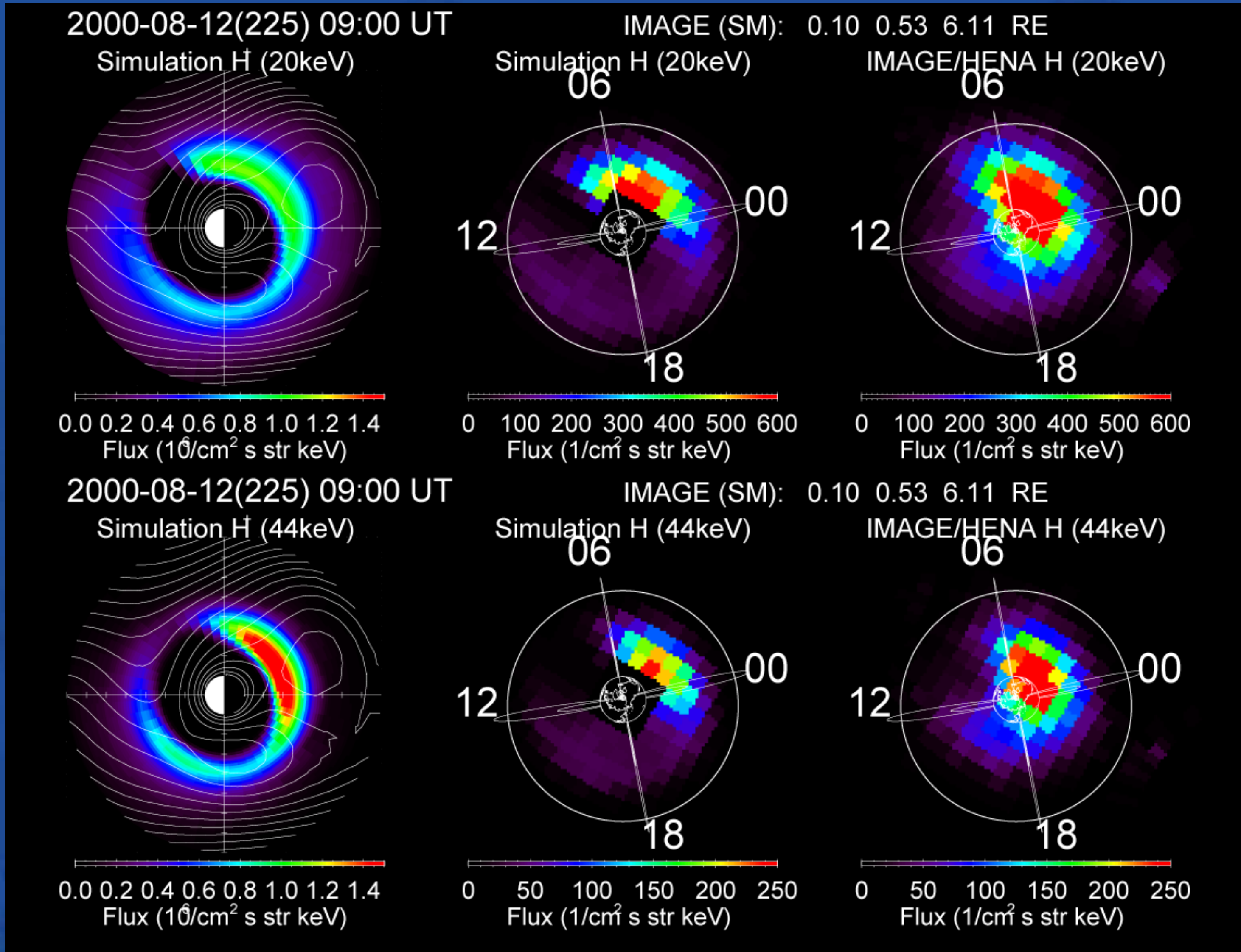
* *SYM-H* index (Kyoto University); IMF from ACE (ACE MFI team)

ENA data are referred to from 9 UT to 12 UT.

Result of data assimilation (UT=9)

16–27 keV

39–50 keV



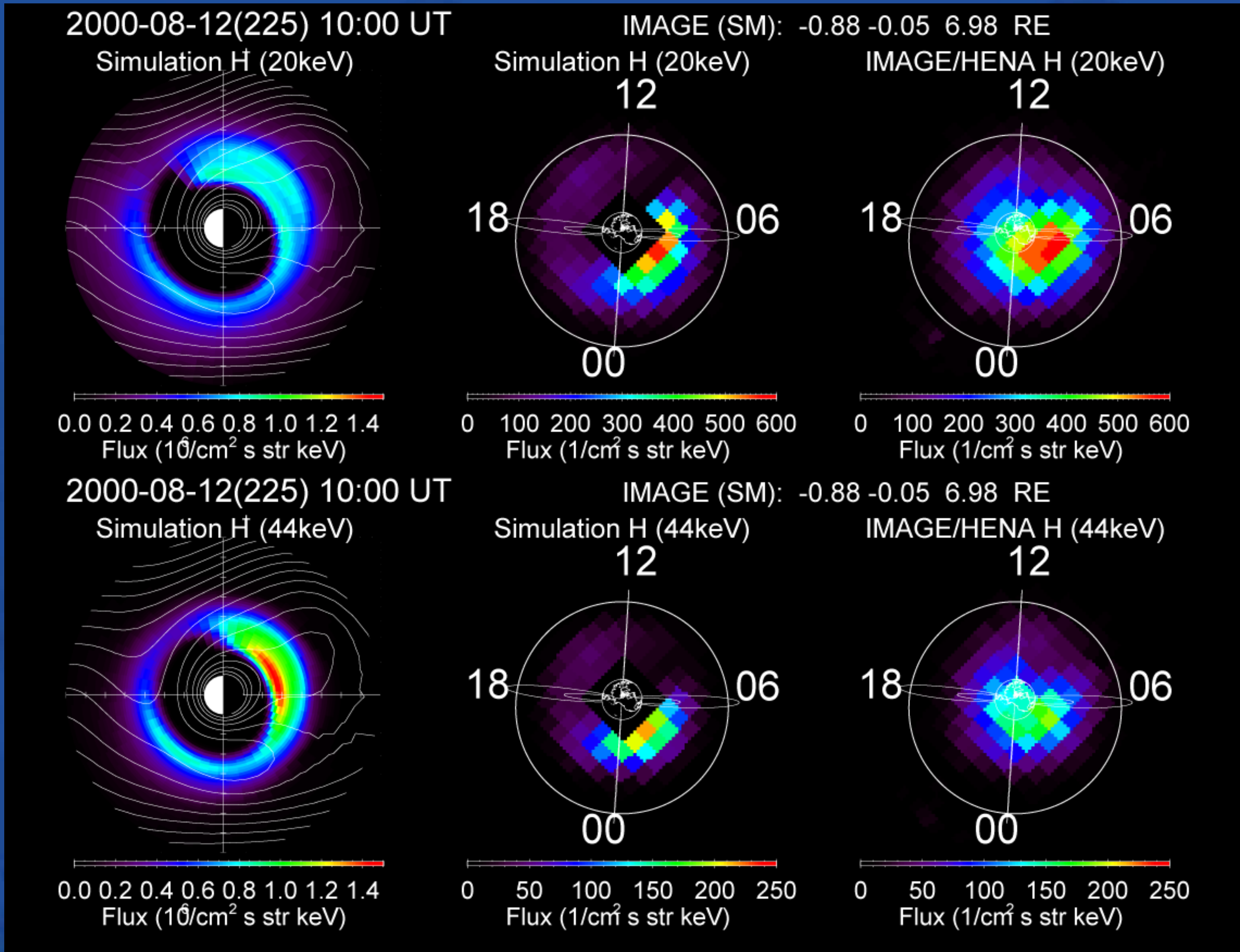
Result of data assimilation

Observation

Result of data assimilation (UT=10)

16–27 keV

39–50 keV



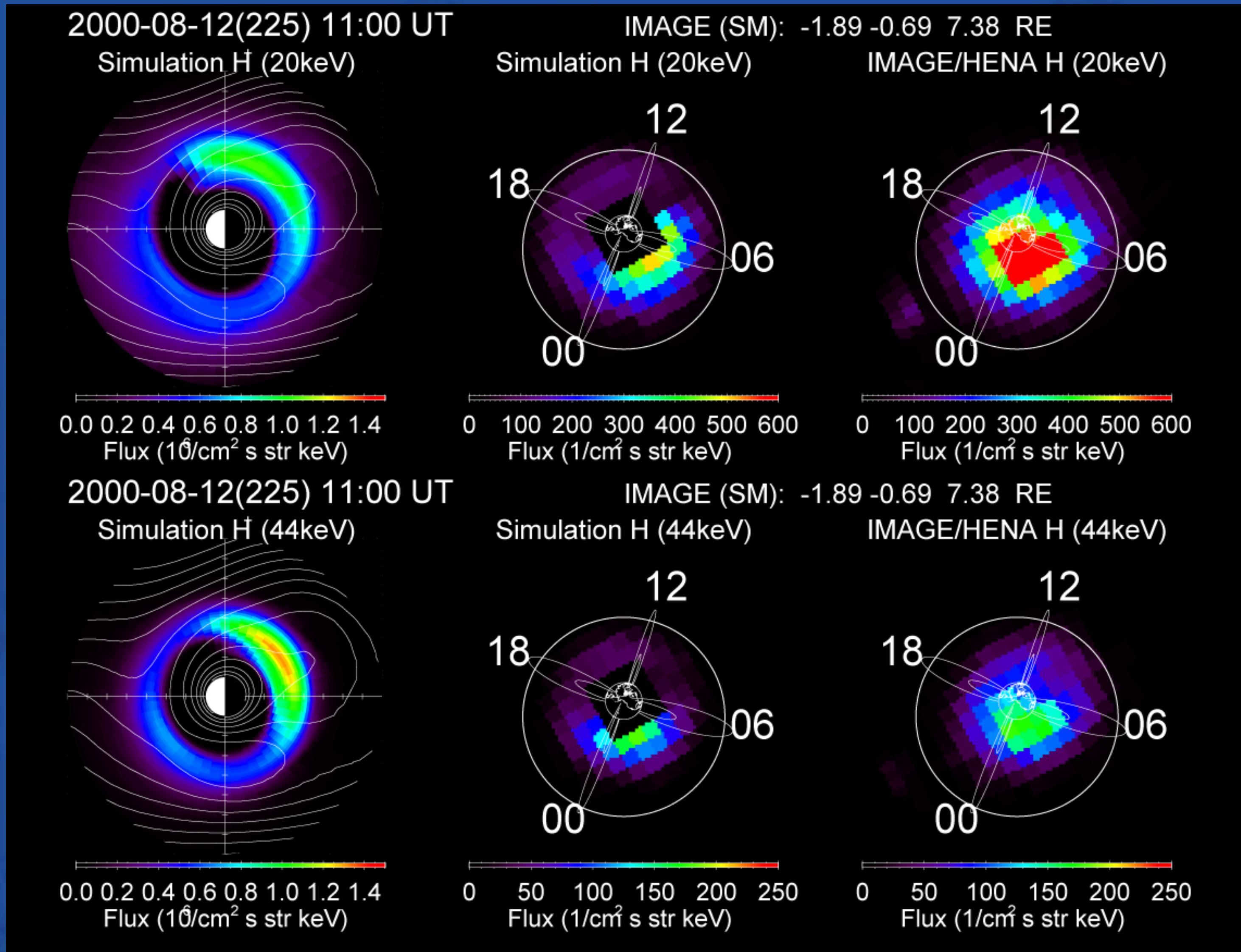
Result of data assimilation

Observation

Result of data assimilation (UT=11)

16–27 keV

39–50 keV



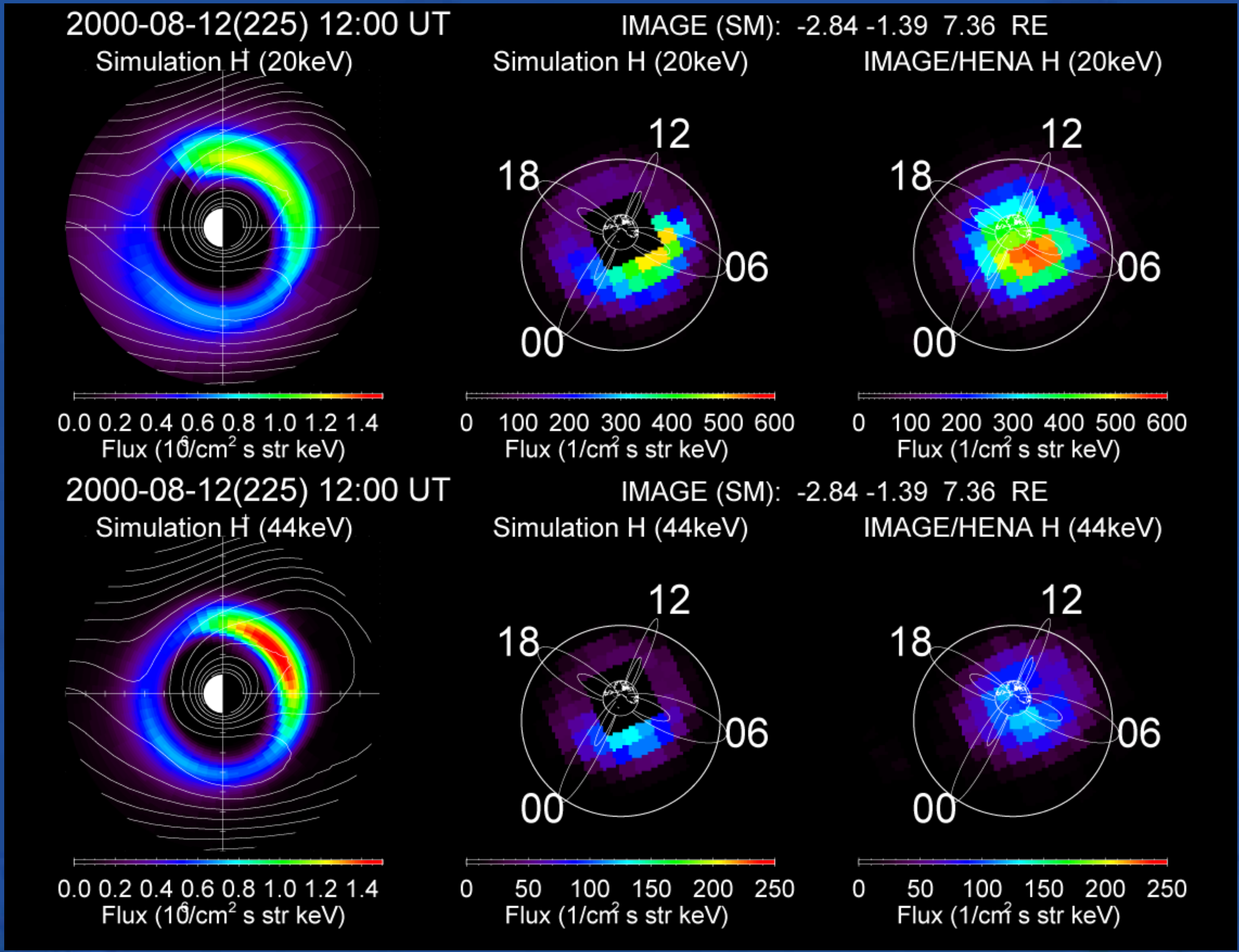
Result of data assimilation

Observation

Result of data assimilation (UT=12)

16–27 keV

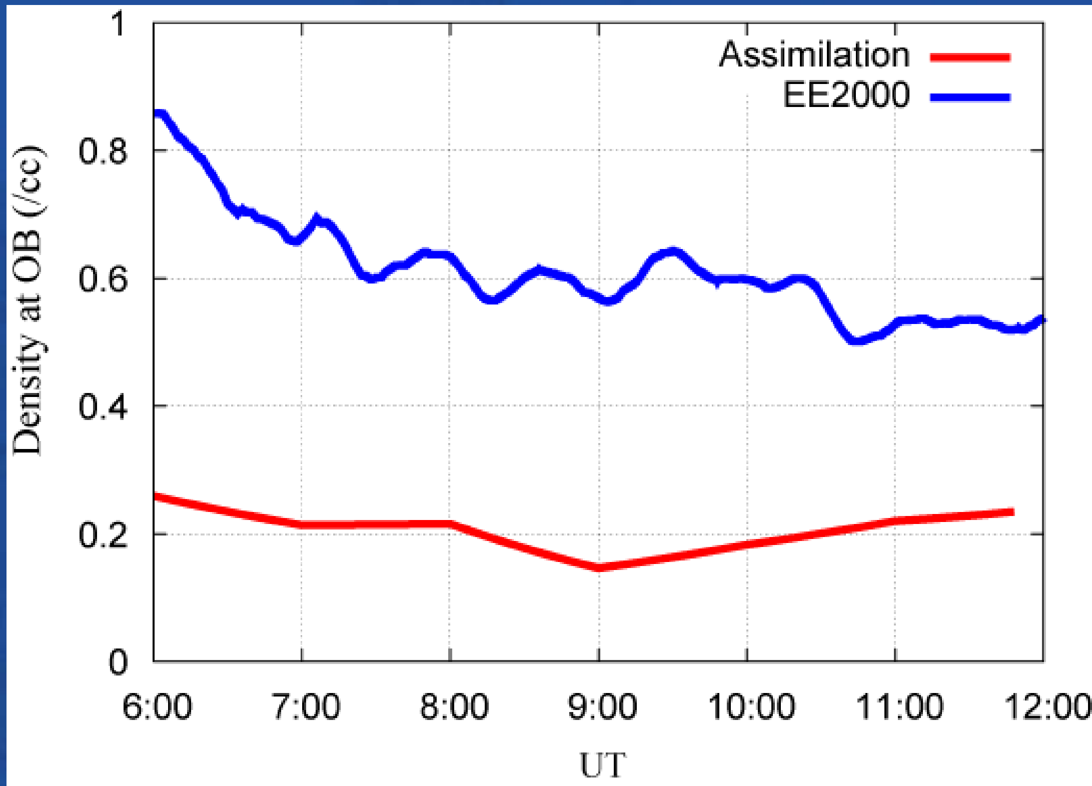
39–50 keV



Result of data assimilation

Observation

Result of data assimilation (Aug. 12, 2000)



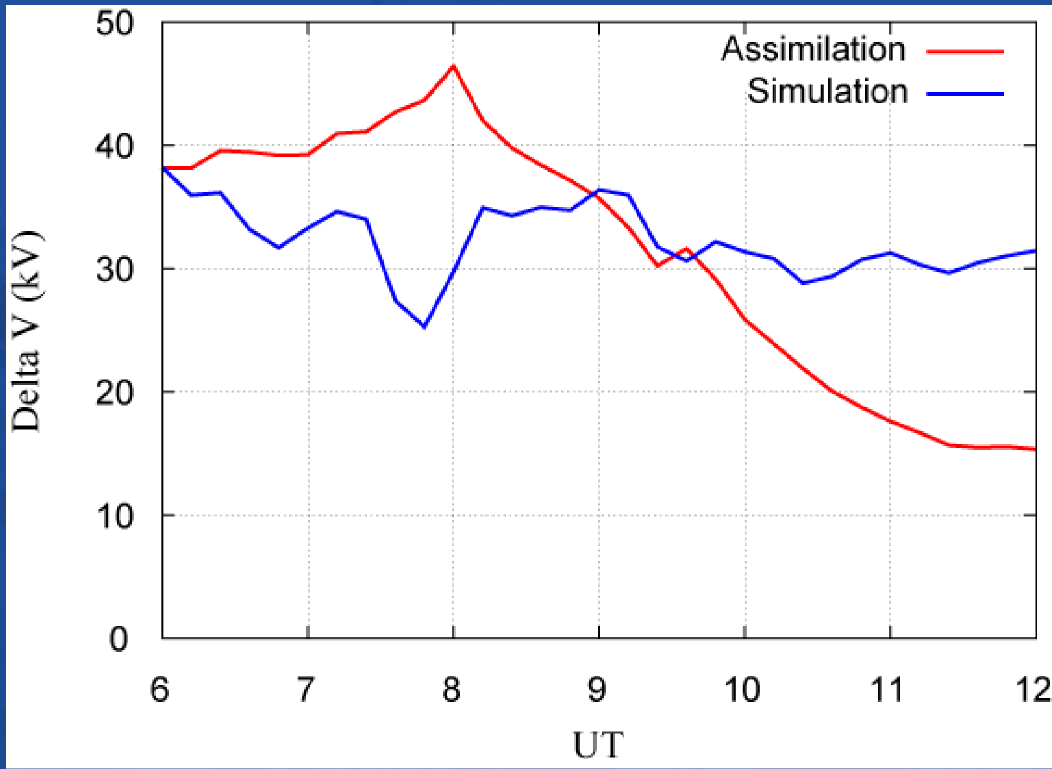
Estimated proton density at the outer boundary (red) and plasmasheet ion density from empirical models

Remarks

- The empirical models of plasmasheet ions do not distinguish among different ion species, and thus it would basically overestimate the amount of plasmasheet protons.
- In addition, Tsyganenko and Mukai (2003) suggests that the prediction of plasmasheet ion density using a statistical model contains large uncertainty, and it might sometimes overestimate the plasmasheet protons.

⟹ Since it is basically difficult to predict the plasmasheet proton density from an empirical model for each event, it would be meaningful to improve the prediction by using data assimilation.

Westward electric field between 0-6 MLT



It is suggested that the electric field decreased steeply in the post-midnight.

Remarks

- It is suggested that the electric field decreased steeply than estimated by the original model.
- The steep decrease of the electric field would depress the acceleration of ring current ions. This would cause the relative decrease of 39-50 keV ENA emission in comparison with 16-27 keV ENA emission.

→ The use of multiple energy channels would be important in resolving the electric field intensity in the inner magnetosphere.

Summary

- ENA data from IMAGE/HENA were assimilated into the CRCM using an algorithm based on a particle filter.
- Ion density was estimated to be about 0.2 /cc, while it was assumed to be about 0.6 /cc in the original simulation. This explains the overestimates of ENA emission in the CRCM.
- It is suggested that the electric field imposed on the magnetosphere decreased rather steeply, which would cause the reduction of 39-50 keV ENA.