Pilot reanalysis of the magnetosphere-ionosphere system and future prospects

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Contents

- Data assimilation into a global magneto-hydrodynamic (MHD) model and development of magnetosphere-ionosphere reanalysis data
- Data assimilation into an emulator of the global MHD model

Motivation

- Available observations are typically sparse especially in the magnetosphere.
- If a numerical model realistically reproduces the temporal evolution of the magnetosphere and ionosphere, the model can be used as a reference to the state of the magnetosphere-ionosphere system.

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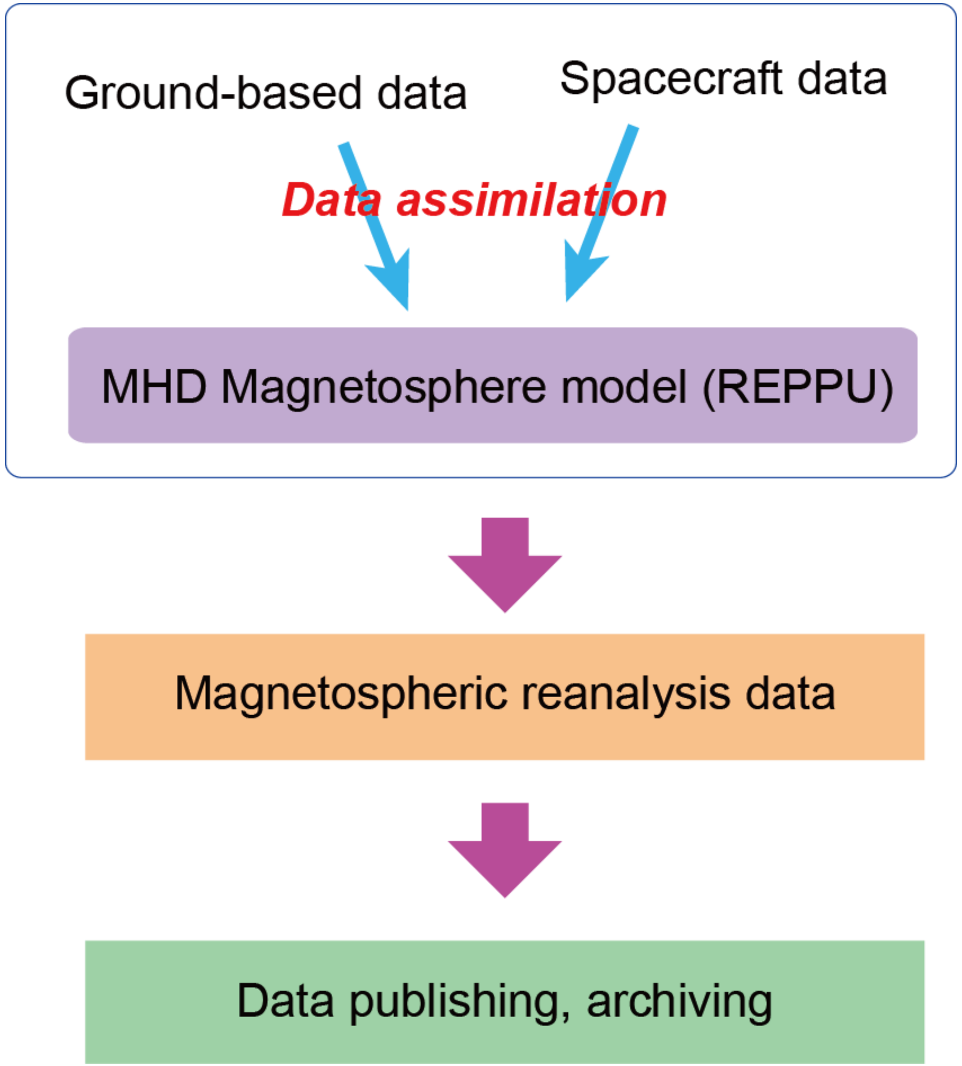
In our project…

- We aim at reproducing the temporal evolution of the magnetosphere-ionosphere system by assimilating real obsevations into a global magneto-hydrodynamic (MHD) model, referred to as REPPU (Tanaka, 2015).
- We also aim at providing the data assimilation products as an open reanalysis data set to the community under the framework of IUGONET.

This study is conducted under Challenge Exploratory Research Projects for the Future supported by Research Organization of Information and Systems (ROIS) (FY2020-FY2022).

Project overview



① First, the global MHD model (REPPU code) (Tanaka, 2015) is improved to consider the deviation of the Earth's magnetic axis from the rotation axis to facilitate the comparison with the observations.

② Second, the values of two parameters are optimized by data assimilation with an ensemble-based variational method.

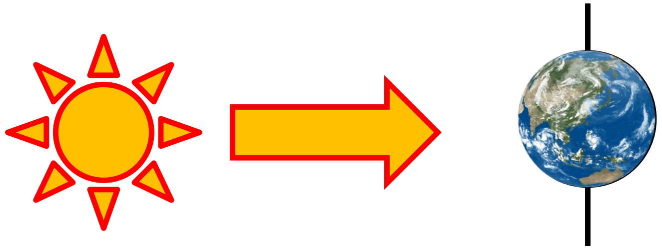
③ Third, we provide the data assimilation products as an open reanalysis data set to the community under the framework of IUGONET.

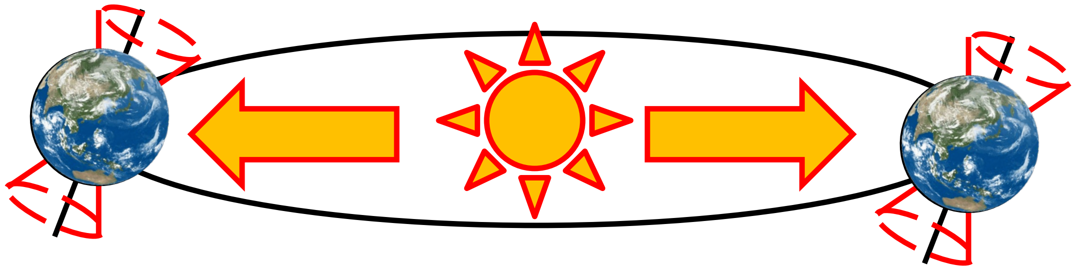
Improve the REPPU code

	Previous version	Improved
IMF	(0, By, Bz)	(Bx, By, Bz)
Flow	(Vx, 0, 0)	(Vx, Vy, Vz)
Rotation axis	Fixed	Inclined with respect to the ecliptic plane
Dipole axis	Identical with rotational axis	Inclined with respect to the rotation axis
Ionospheric conductivity	Fixed	Changed according to the solar zenith angle

*Dipole axis was determined from IGRF 2000

Rotation axis = Dipole axis





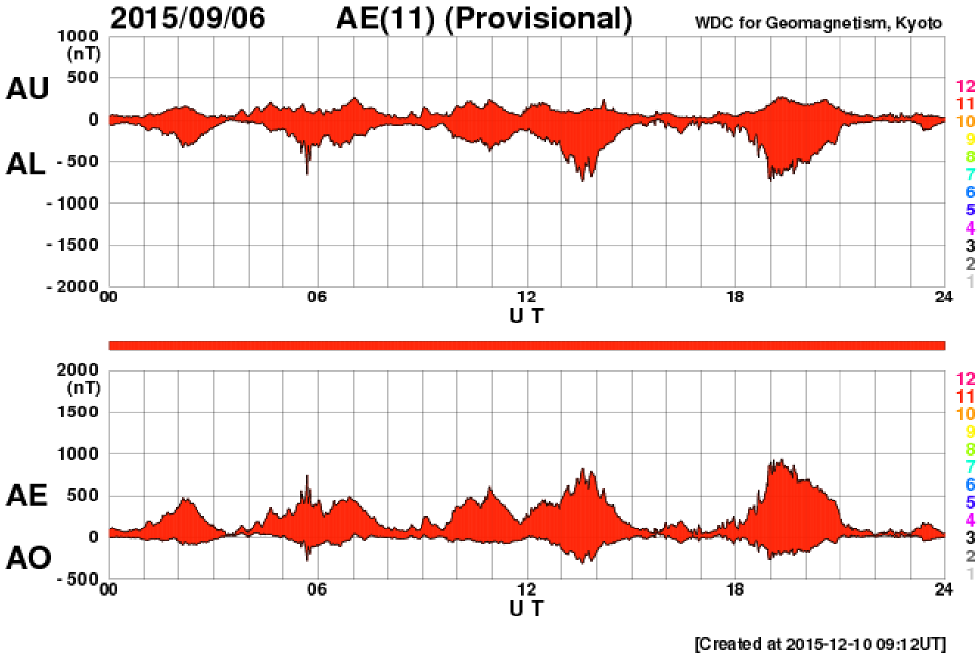
Incilned dipole axis

Data assimilation design

- Model: improved REPPU code
- Data: SuperDARN map potential data, AMPERE field-aligned current data.
- Two parameters describing ionospheric conductivity are estimated by data assimilation with the ensemble-based variational method .

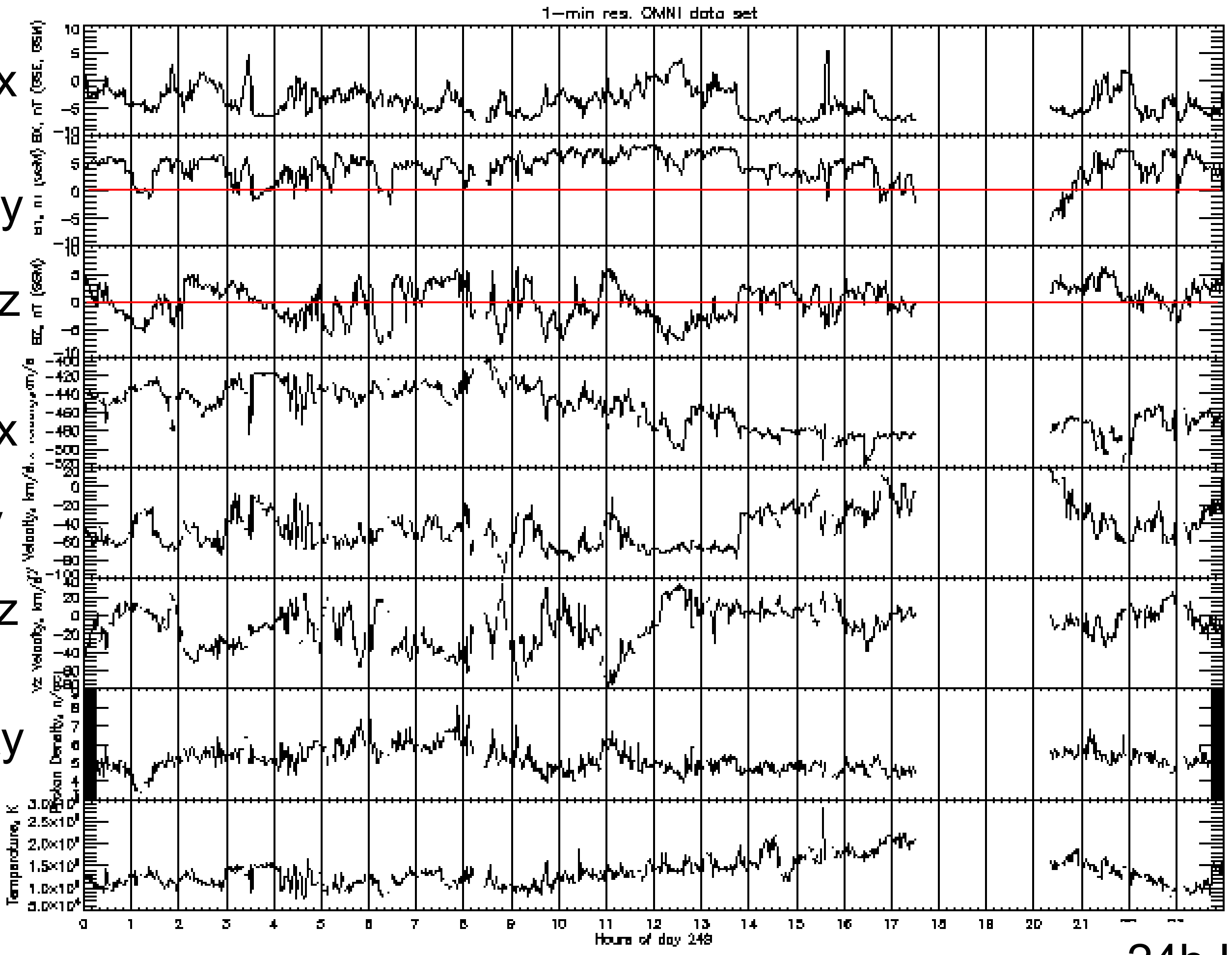
Event overview

6 Sep. 2015



Auroral Electrojet (AE) Indices

Bx
By
Bz
Vx
Vy
Vz
density
temp.

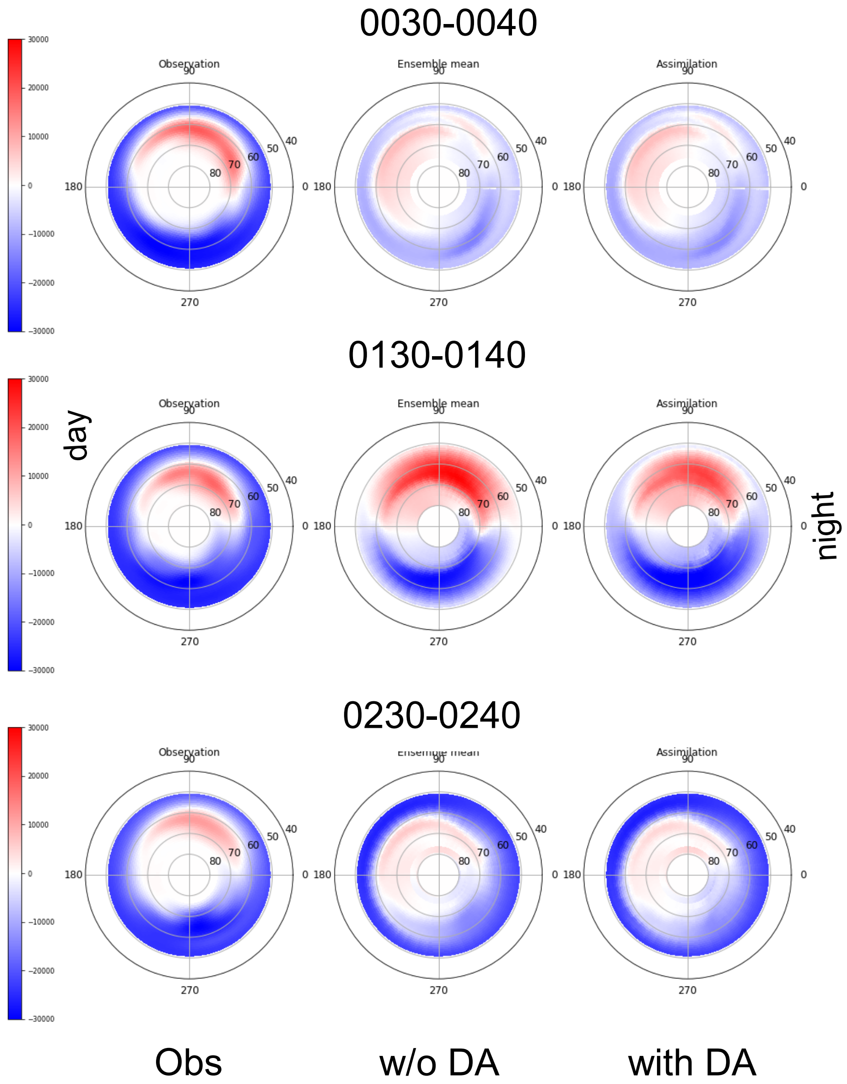


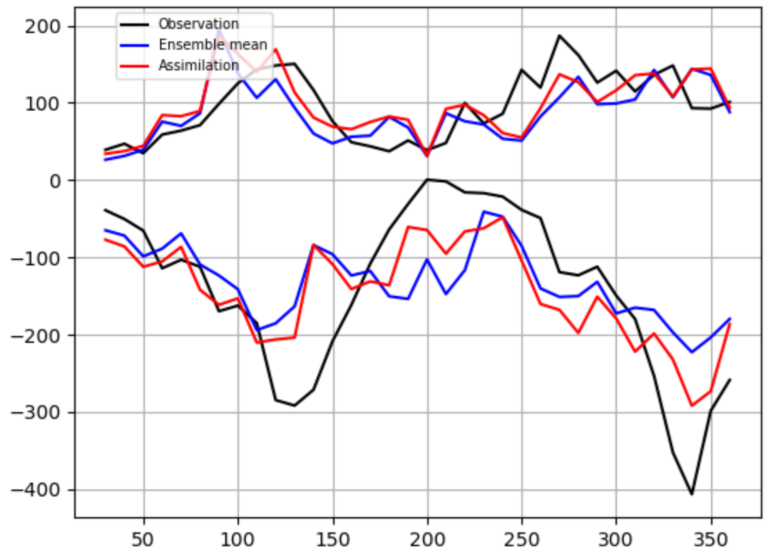
0h UT

24h UT

Solar wind data (OMNI level2)

Data assimilation result

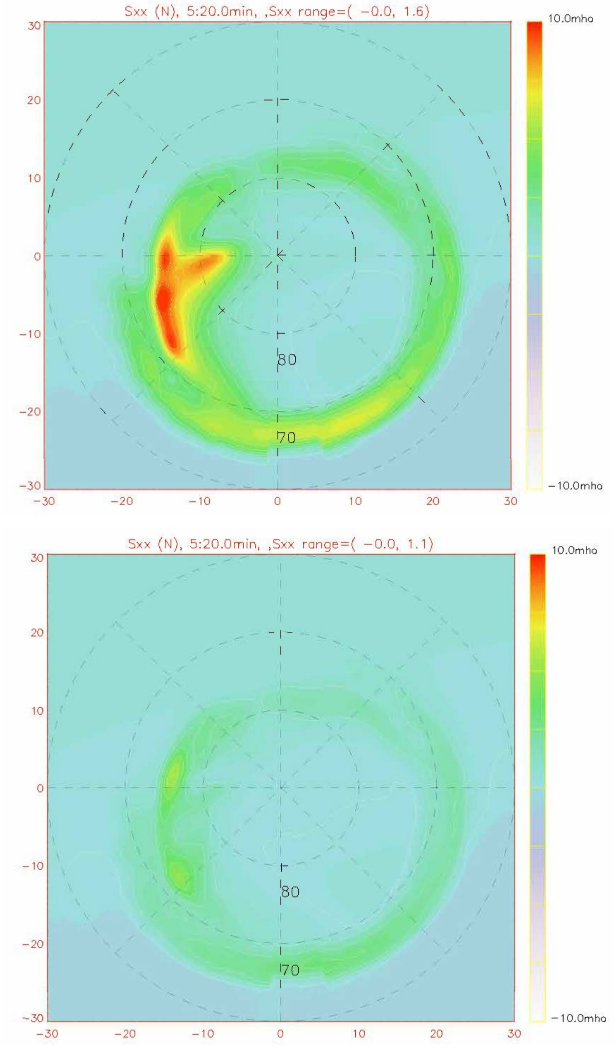




Observed AU/AL indices (black), simulation without data assimilation (blue), and data assimilation result (red) for the period from 0030-0610 UT, on 6 September 2015.

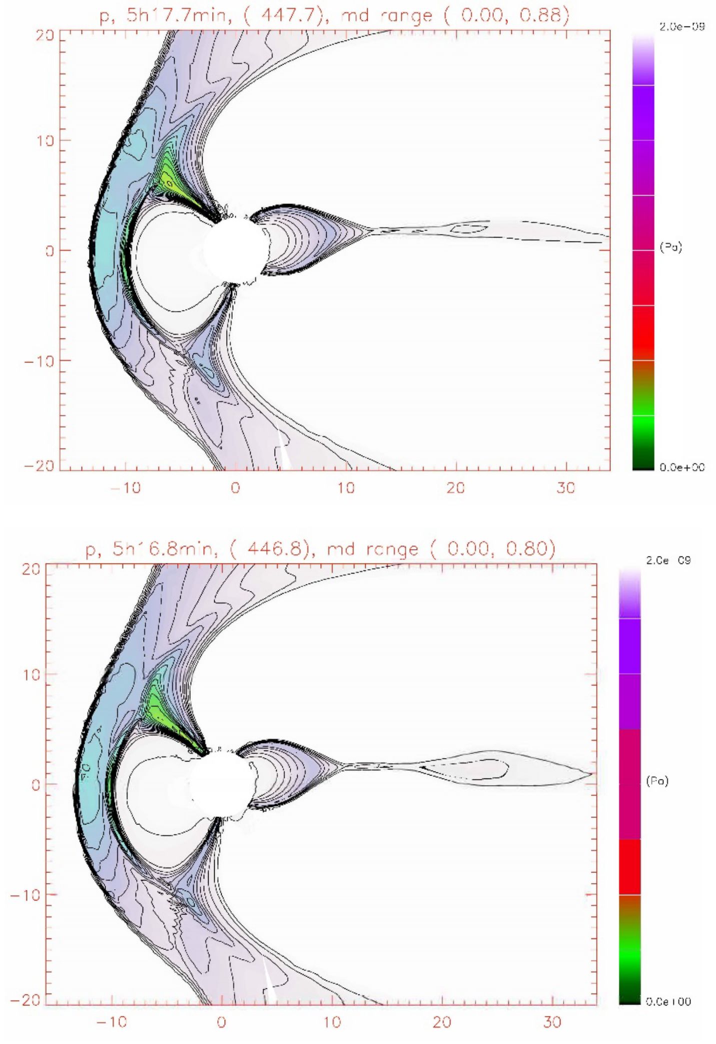
- Electric potential maps derived from SuperDARN data and AU/AL data were assimilated into the MHD model.
- The parameters representing ionospheric conductivity were optimized by data assimilation.

Data assimilation result



With DA

w/o DA



Ionospheric Pedersen conductivity

Pressure on the meridional plane

- Ionospheric conductivity gets larger as a result of data assimilation, which improves the problem that the REPPU code tends to overestimate ionospheric electric field.
- Data assimilation does not affect the pressure distribution in the magnetosphere.
- We have achieved to estimate ionospheric conductivity with data assimilation into a global MHD model for the first time in the world.

Pilot reanalysis dataset

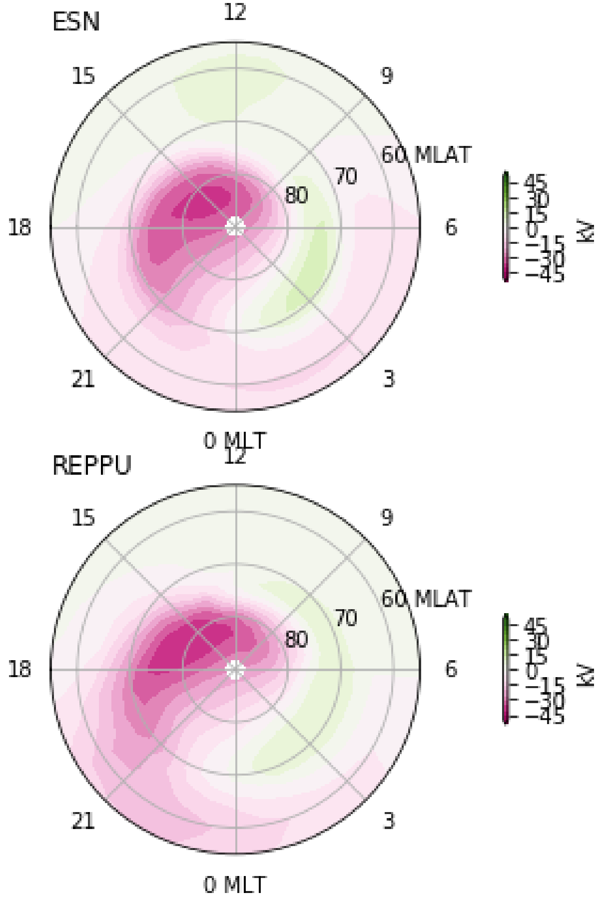
- A pilot reanalysis dataset (for the event on 6 Sep 2015) is now available on the IUGONET website as below.
  http://iugonet0.nipr.ac.jp/data/reanalysis/
- Sample programs for reading the dataset are also available.
  https://github.com/iugonet/Udas/tree/master/iugonet/tools

Problems of the DA into the global MHD model

- The REPPU simulation takes too long time to calculate.
(> 40 hours for real 8 hours with a supercomputer).
- Moreover, we need to repeat simulation runs many times to estimate a large number of variables with data assimilation.
(20 ensemble members were used in our reanalysis.)
- For these reasons, data assimilation into the MHD model can substantially improve only a few parameters of the model.

Emulator of the global MHD model

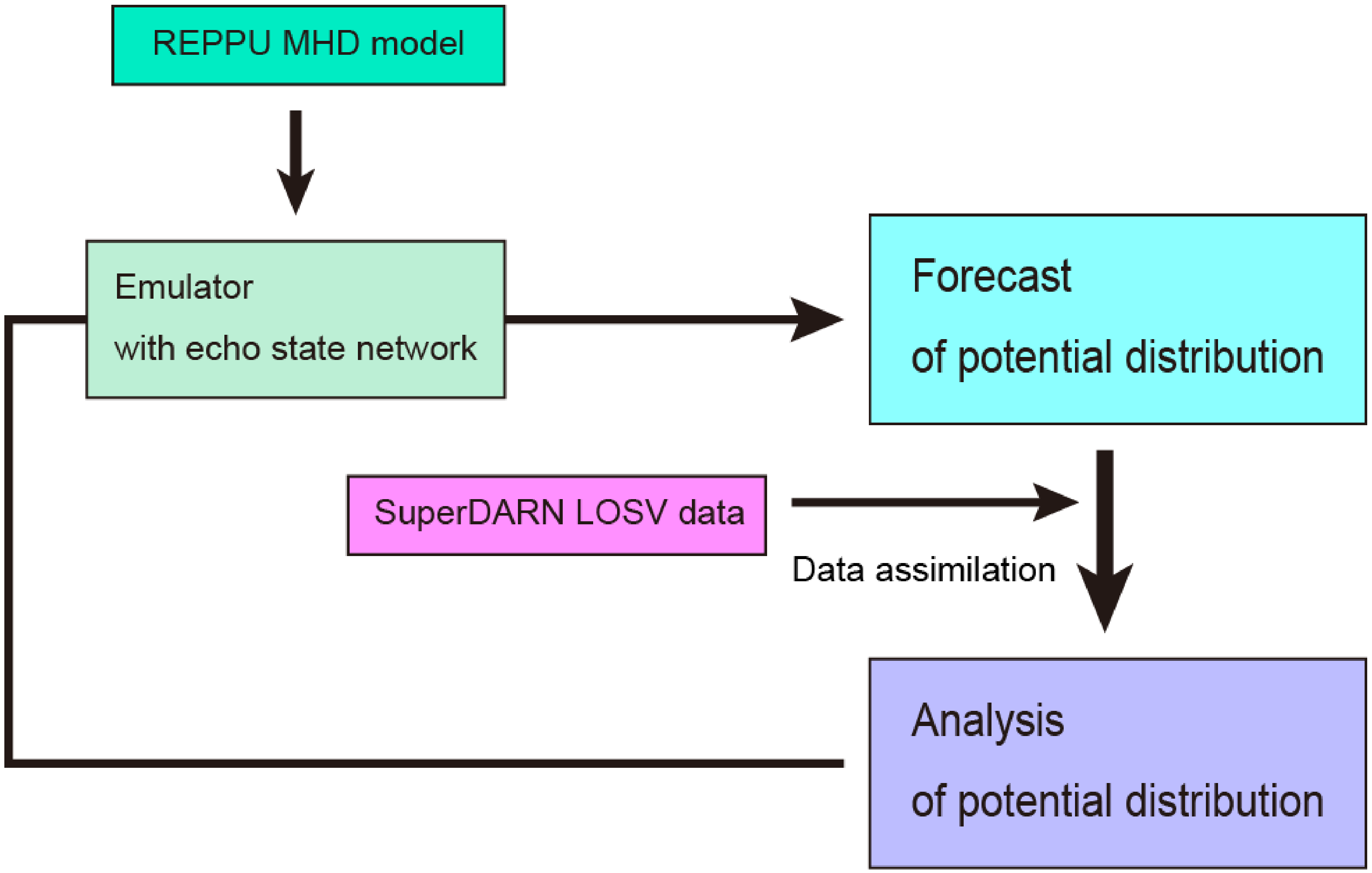
- To overcome the problem of the computational cost, we are developing an emulator, which mimics outputs of the REPPU simulation model (Kataoka et al., submitted).
- A prediction of the two-dimensional ionospheric structure is feasible with the emulator!
- Assimilation of ionospheric data into the emulator would also be possible.



Emulator output (upper); Simulator output (lower)

(Kataoka et al., submitted)

Combining data with an emulator

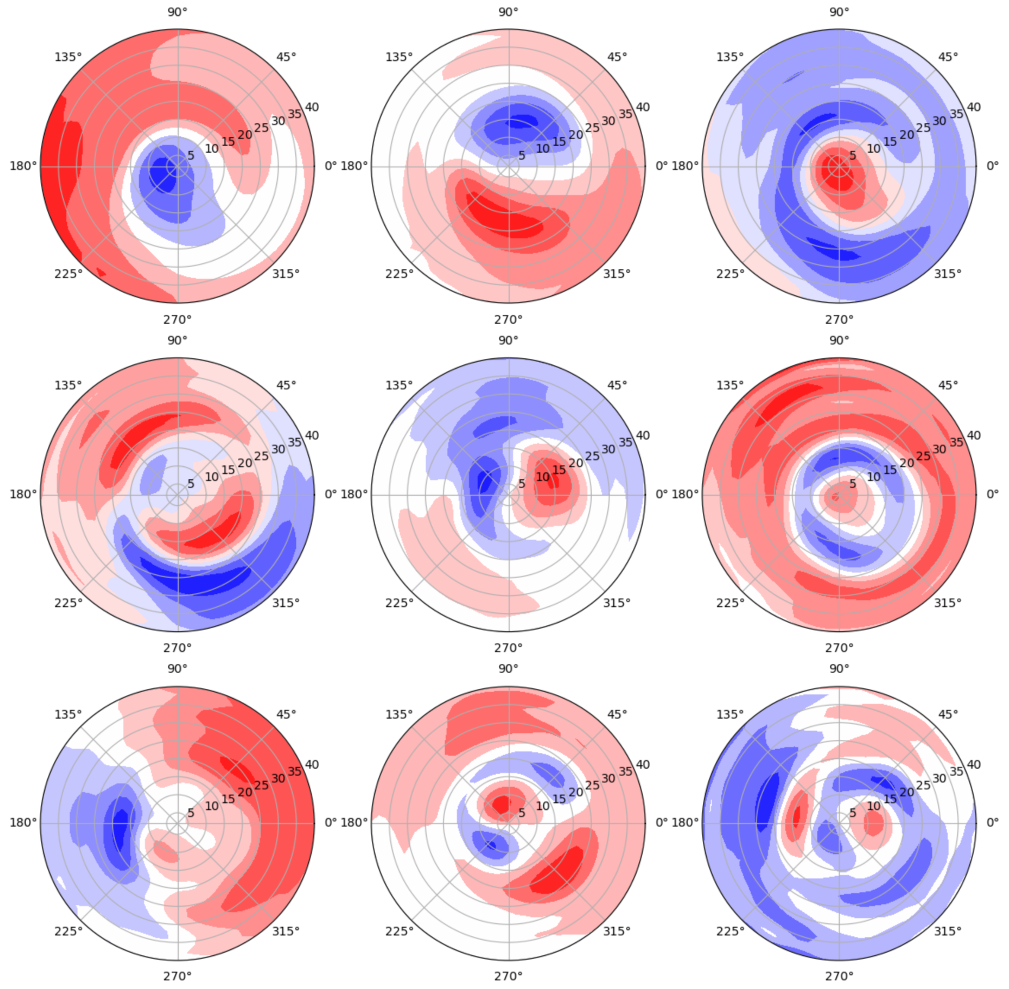


Emulating the MHD model

1. Principal component analysis is applied to field-aligned current disitribution and ionospheric potential distribution of simulation outputs.
2. The relationship between solar wind inputs and the principal component coefficients is described with a machine learning model.

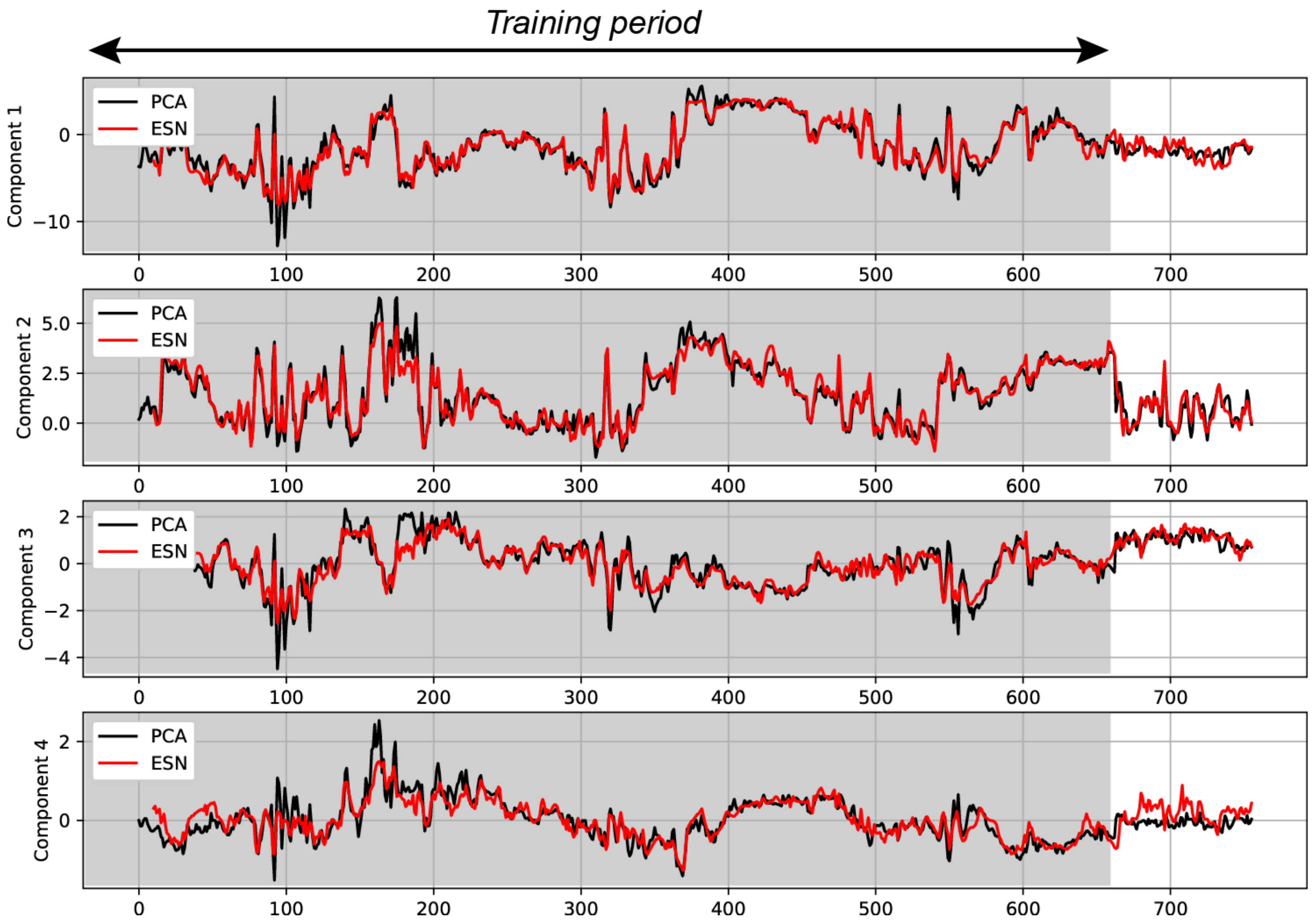
The echo state network is employed for learning the relationship between the solar wind and the principal component coefficients.

➡ We can predict the potential distribution given a time sequence of solar-wind parameters.



Principal components for potential

Performance of the emulator



Data assimilation into the emulator

1. An ensemble of emulations is generated by adding perturbations in solar-wind inputs.
2. Each principal components of electric potential is expanded with a set of basis functions proposed by Nakano et al. (2020).
3. The line-of-sight velocity data from SuperDARN are incorporated into the prediction by the emulator with the ensemble Kalman filter (with 18 members).

DA into the MHD model (～40hours × 20 members with a supercomputer)

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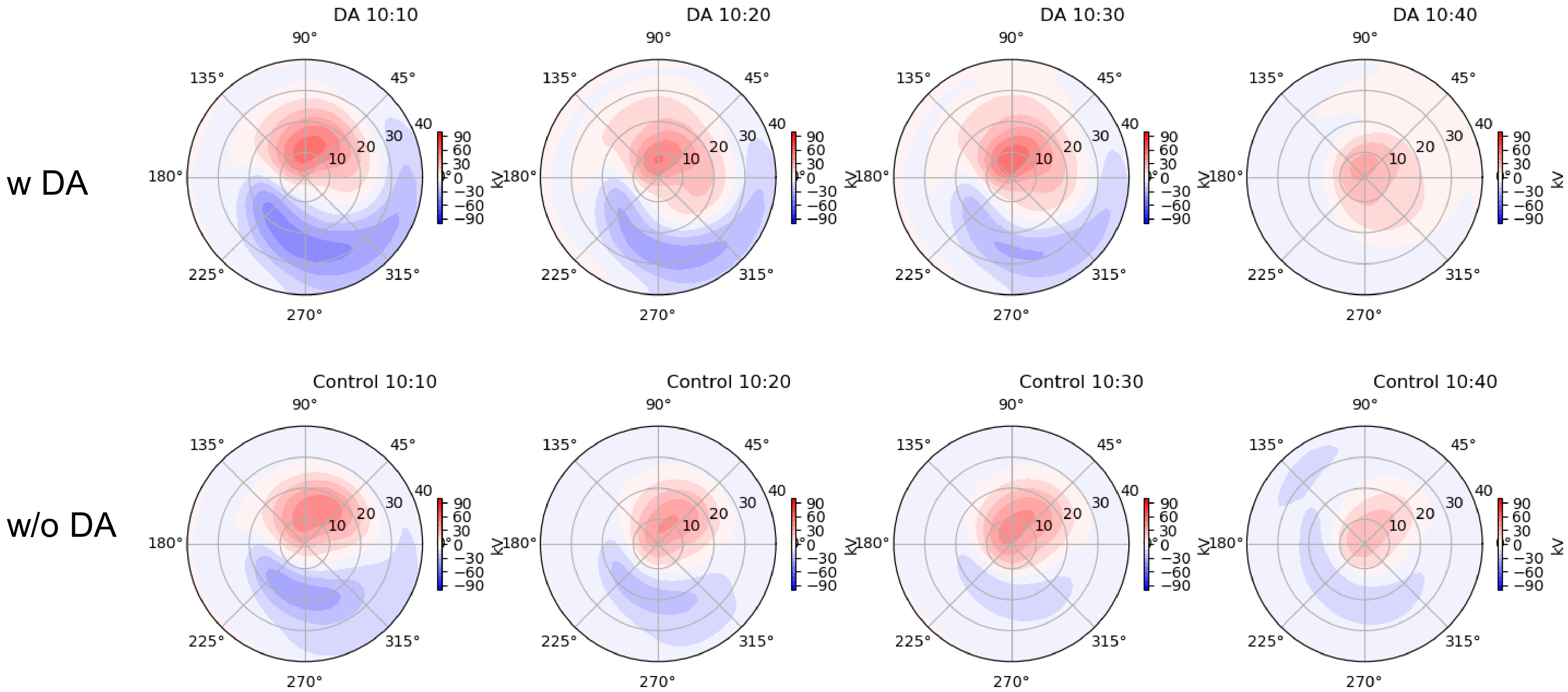
DA into the emulator (< 20 seconds with a workstation)

Preliminary result of assimilation into the emulator



Estimate for the event on 27 March 2017

Summary

- We are conducting a research project which aims at reproducing the temporal evolution of the magnetosphere-ionosphere system by assimilating real obsevations into a global MHD model.
- We are also developing a new technique which combines ionospheric observations with an emulator of the global MHD model.
- The use of the emulator is a promising approach to obtaining a realistic estimate of the ionospheric state.
- SuperDARN data will play an important role for developing reanalysis data because of large spatial coverage.