Multivariate autoregressive (AR) prediction of MeV electron flux variation in Geostationary and Medium Earth orbits

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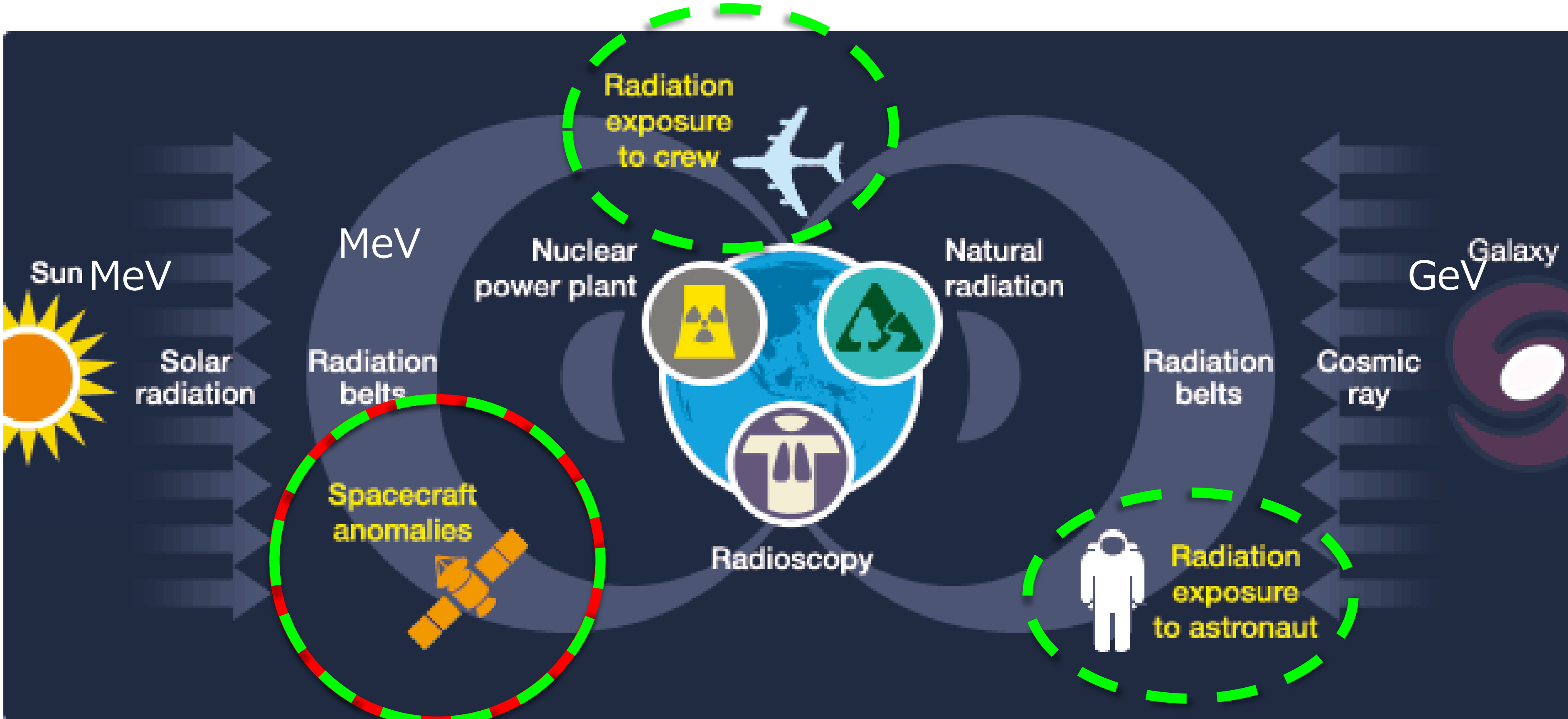
Outline

- Introduction
  - Satellite Anomaly
  - New particle observation by Himawari/SEDA
- Method and results of our model
  - Himawari/SEDA
  - Van Allen Probes
- Summary

High-energy particles in Geospace and risk for space utilities



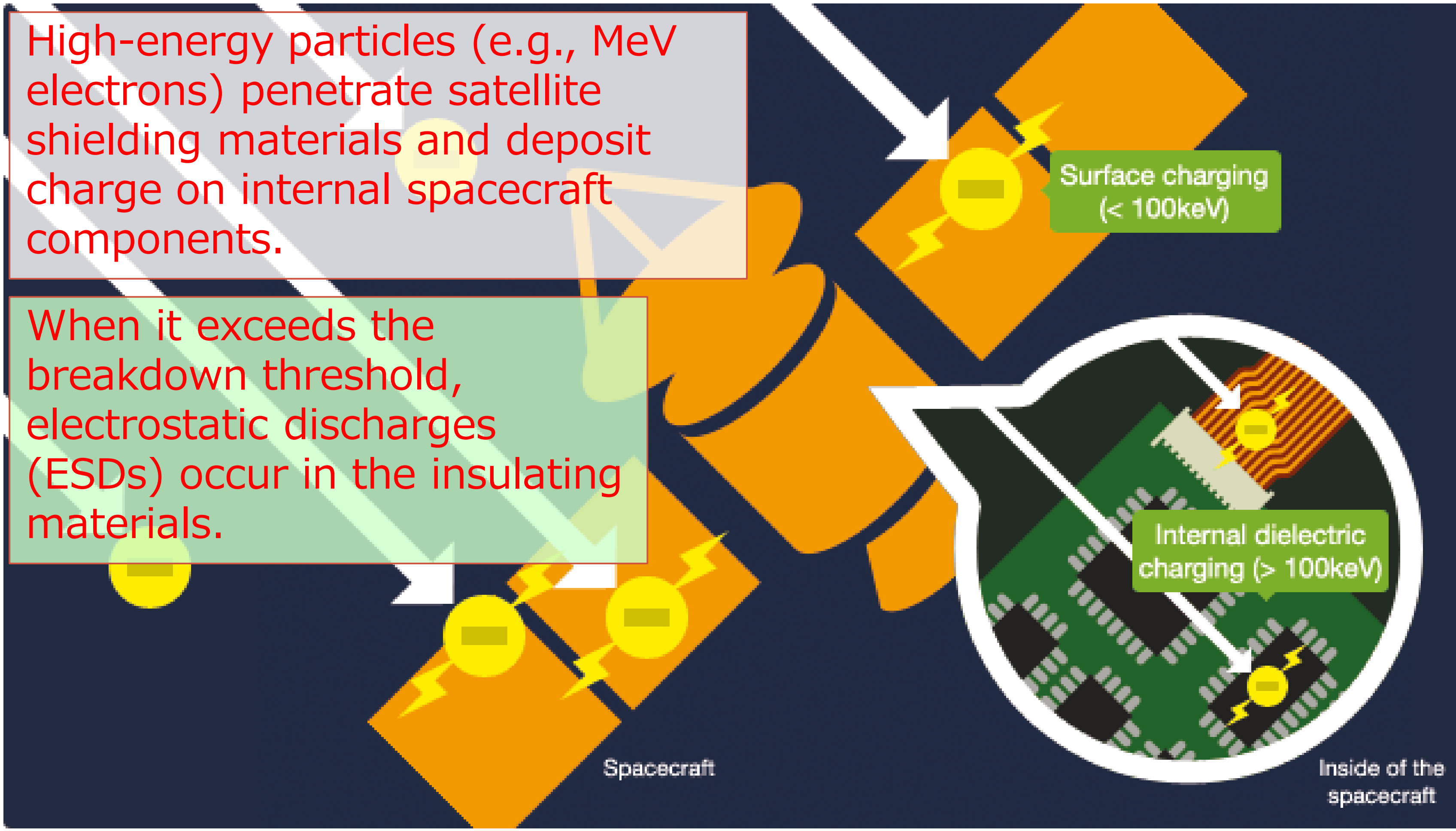
↑

Topic of this presentation (radiation belt electrons)

Spacecraft anomaly by deep dielectric charging

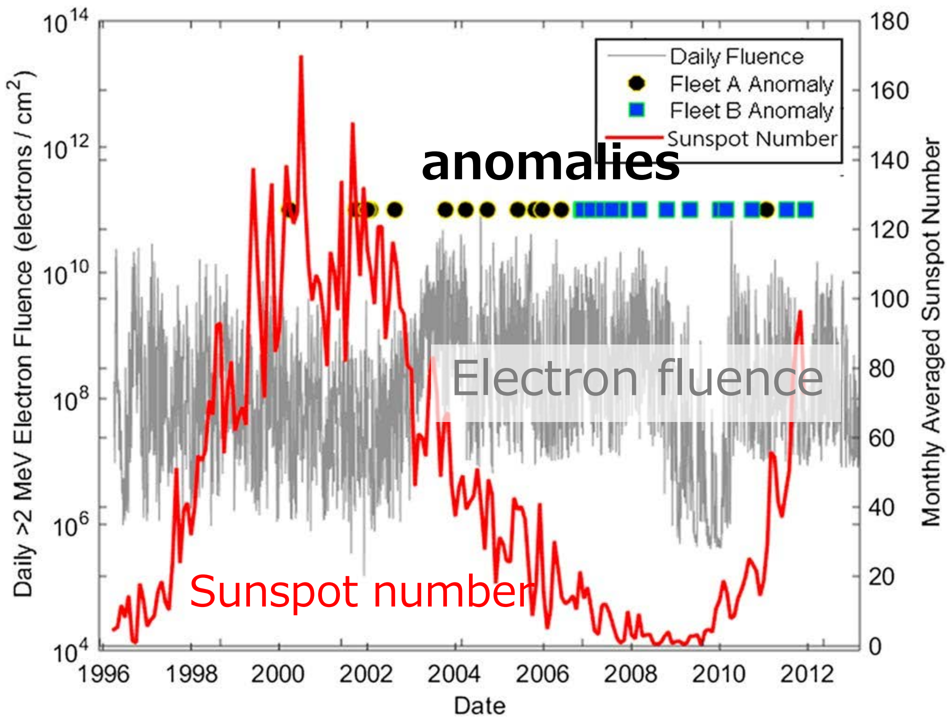
High-energy particles (e.g., MeV electrons) penetrate satellite shielding materials and deposit charge on internal spacecraft components.

When it exceeds the breakdown threshold, electrostatic discharges (ESDs) occur in the insulating materials.



Examples of anomalies:

Communications satellites at GEO [*Lohmeyer and Cahoy, 2013, 2015*]

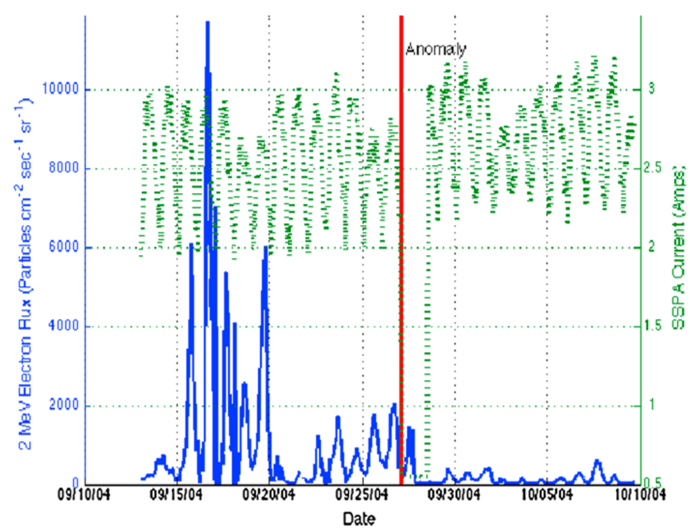


wn in red.

Lohmeyer and Cahoy, 2015

Inmarsat
power amplifier anomalies

- ✓ frequently occur in the declining phase of solar cycle.
- ✓ tend to occur electron fluence accumulated over 14 and 21 days.



Lohmeyer and Cahoy, 2013

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Energetic particle monitoring over Japan by the meteorological satellite HIMAWARI-8

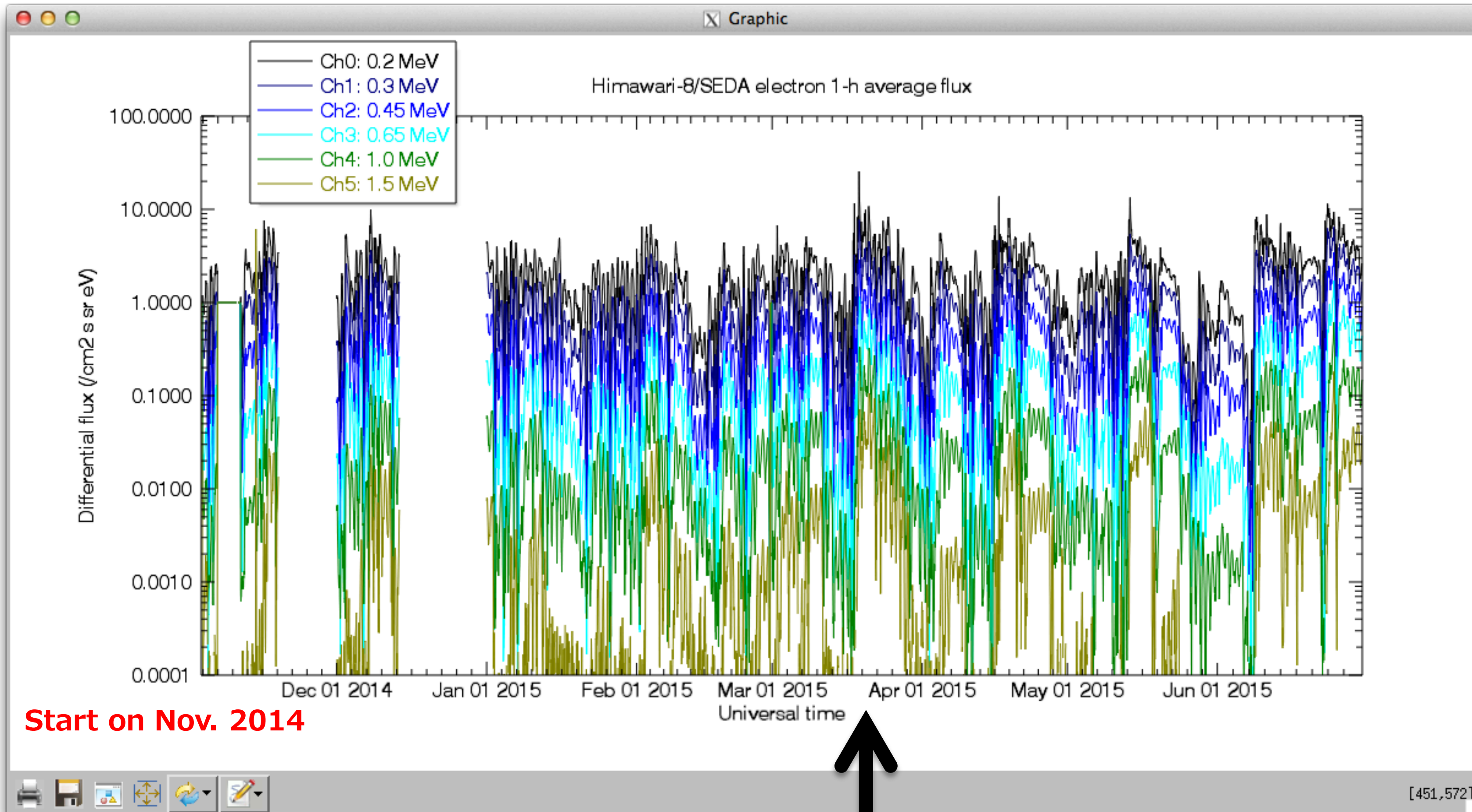
- **Instrument: SEDA（Space Environment Data Acquisition monitor）**
- **Purposes: house-keeping and failure analysis**
- **Launch: 2014/10/07, Himawari-9 Launch; 2016 (plan)**
- **Longitude: ~140 deg.**
- **SEDA data is available from Nov. 03, 2014**
- **Near-real time SEDA data is archived at NICT.**

electron sensors

proton sensors

Electrons: 8 ch. (8 series plate)
Protons: 8 ch. (8 sensors)
Electrons: 0.2 MeV ~ 5 MeV
Protons: 15 MeV ~ 100 MeV
Electron sensor: ± 78.3°
Proton sensor: ± 39.35°
Time resolution: 10 s

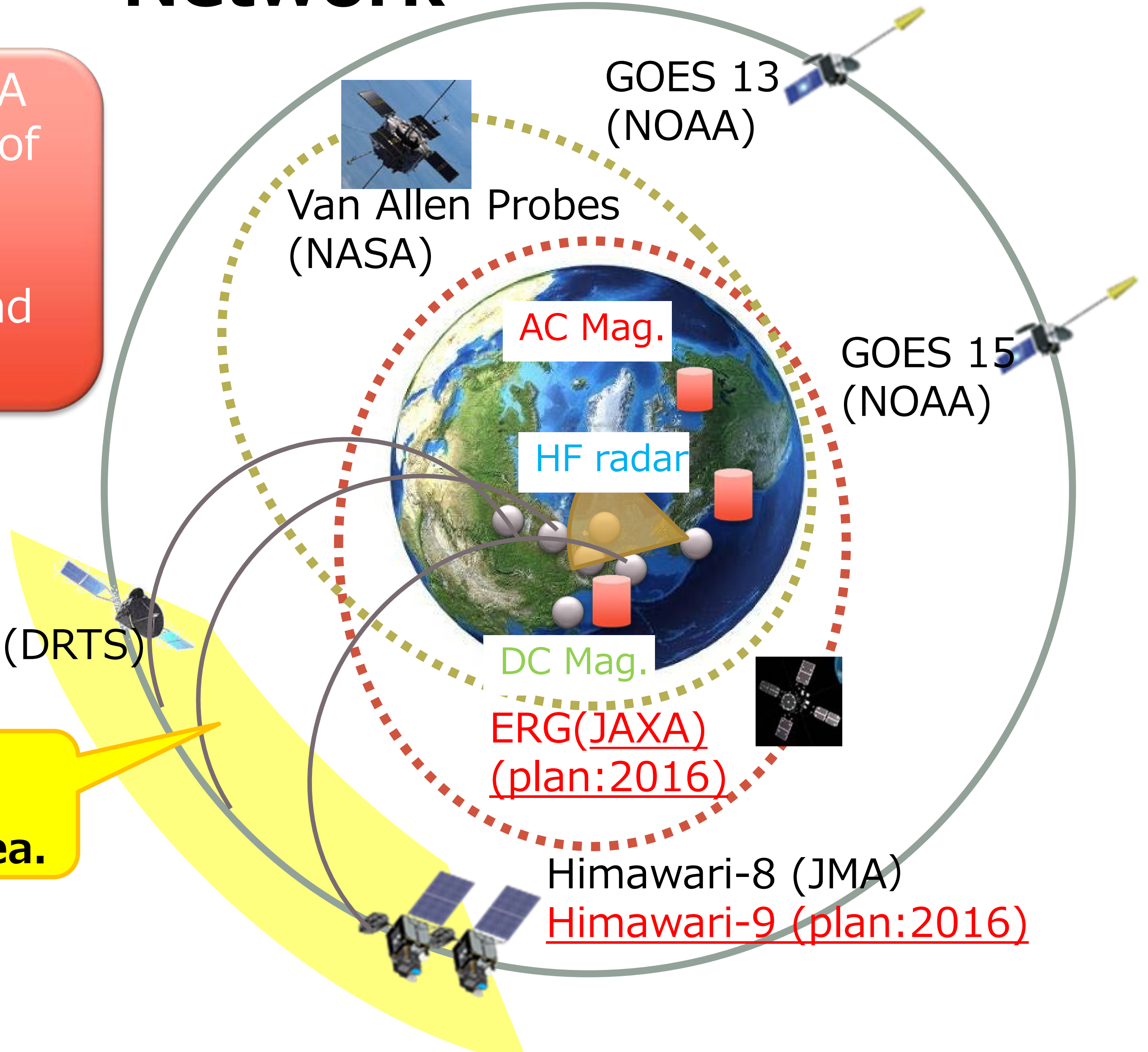
SEDA observation data electron flux (0.2 – 1.5 MeV)



After St. Patrick's day storm

3-Dimensional Geospace Monitoring Network

Himawari-8/SEDA data as a source of global space environment monitoring around GEO,



Japanese GEO Satellites are operated in this area.

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How to Predict?

- ✓ Numerical simulation?
- ✓ Empirical model?

Multivariate autoregressive (AR) model + Kalman filter

Autoregressive (AR) model can estimate future flux variations on the basis of its lagging correlation with changes in other parameters [Sakaguchi et al., 2013].

$$\mathbf{Y}_t = \sum_{n=1}^{m} \mathbf{A}_n \mathbf{Y}_{t-n} + \mathbf{v}_t,$$

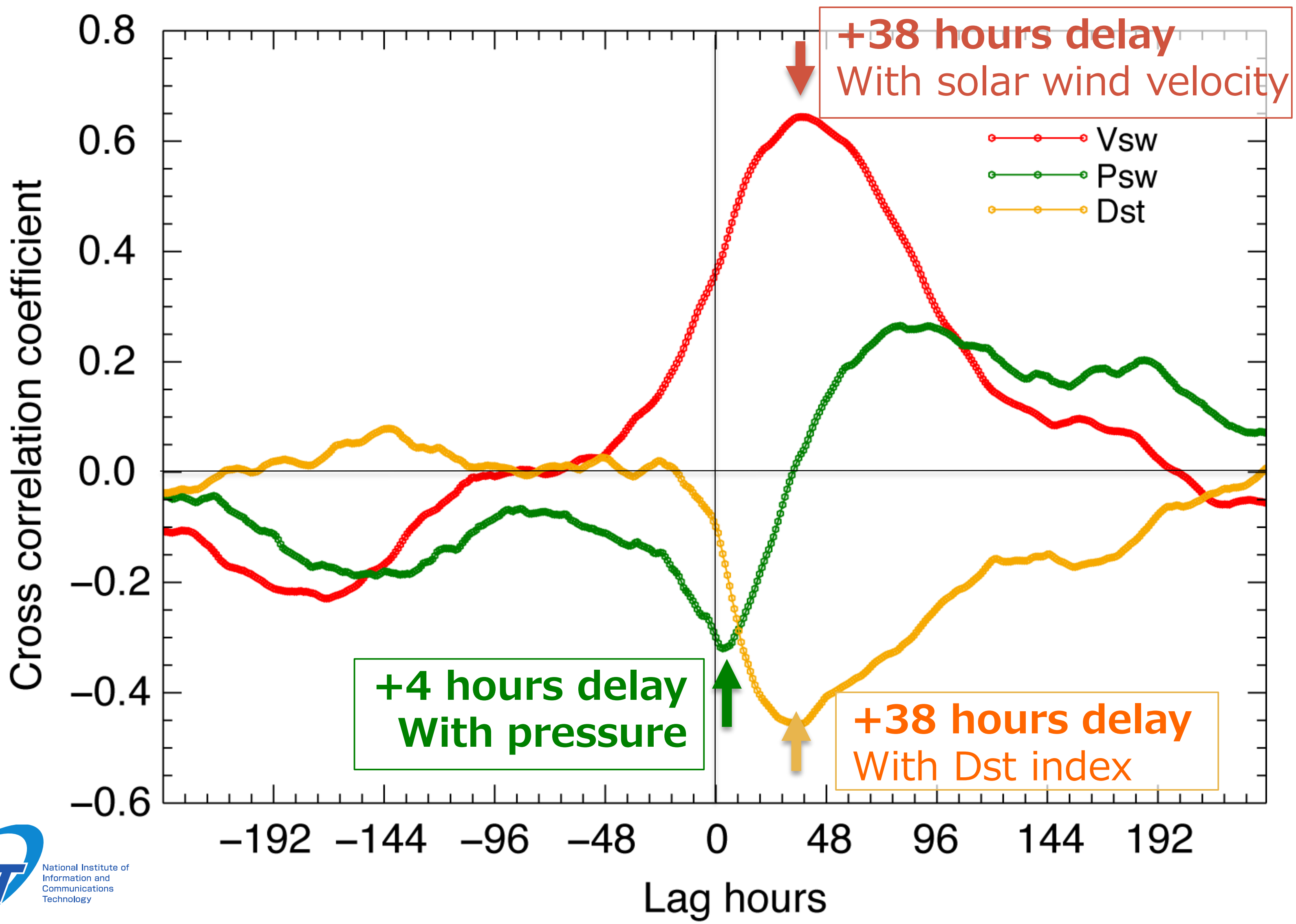
$$\mathbf{Y} = \begin{bmatrix} y_1 & \cdots & y_k \end{bmatrix}^{-1}$$

y_1: predictor variate (flux)

y_k: explanatory variate (solar wind)

- ✓ Daily average electron flux variations correlate positively with corresponding averages of the **solar wind flow speed** near the Earth [e.g., Paulikas and Blake, 1979]
- ✓ Relativistic electron flux largely decreases, when the **solar wind dynamic pressure** increases. [e.g., Turner et al., 2012].
- ✓ The high-speed solar wind stream with **southward offset in the IMF B_Z** enhances the electron flux more than that without offset. [Miyoshi and Kataoka, 2005]

Cross-correlation functions between
HIMAWARI SEDA electron flux and other parameters



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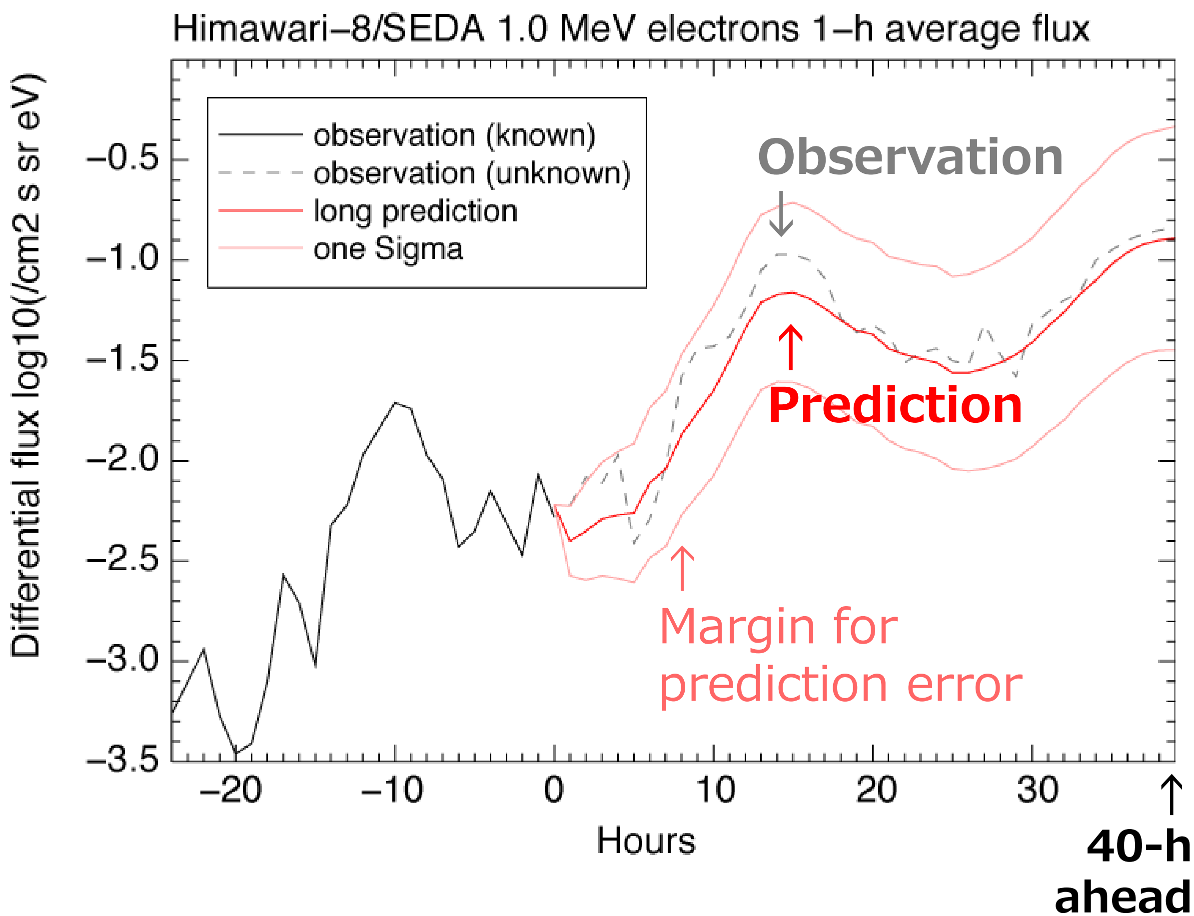
Time series prediction result of GEO MeV flux by AR model + Kalman filter



$$\mathbf{Y}_t = \sum_{n=1}^{m} \mathbf{A}_n \mathbf{Y}_{t-n} + \mathbf{v}_t,$$

Regression order
- **28 hours**

Inputs
- **Solar wind velocity**
- **Solar wind pressure**
- **Dst index**

#Coefficient matrix A is estimated by the least square method

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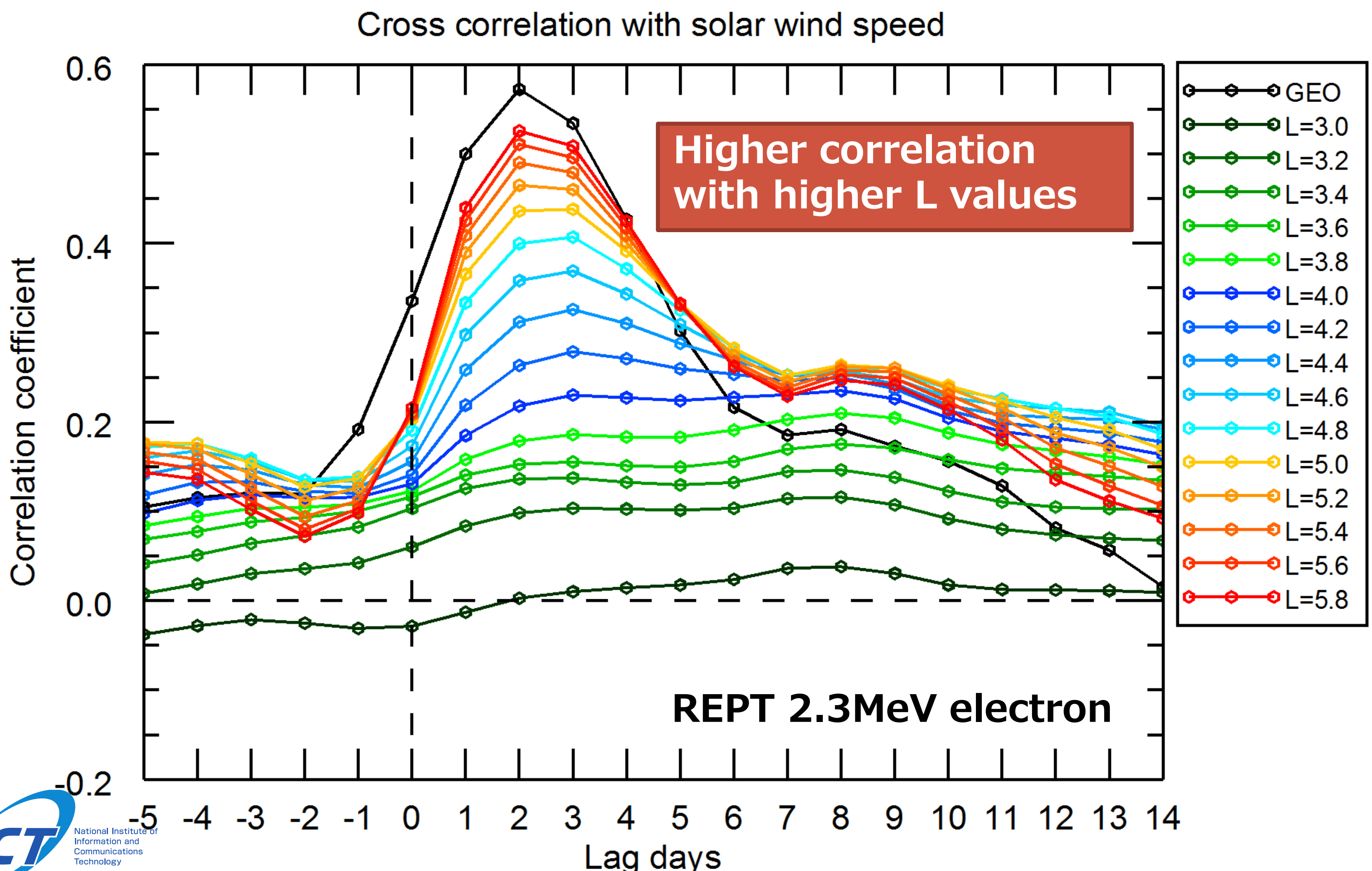
Cross correlation functions w/ Vsw
for each L shell (by Van Allen Probes data)



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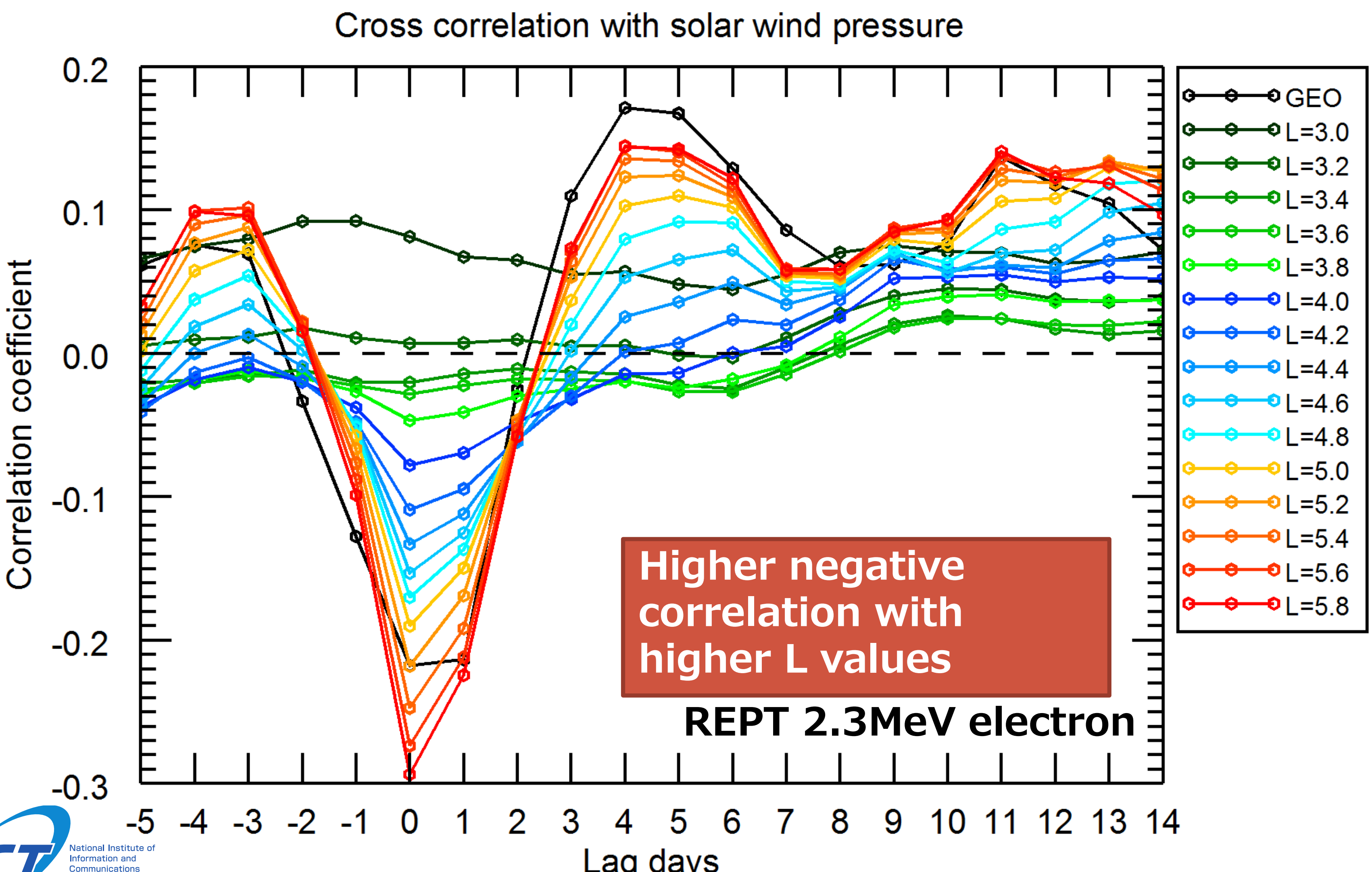
Cross correlation functions w/ Psw
for each L shell (by Van Allen Probes data)



Effective combinations of input parameters

L values	Regression	Input parameters
L=3.0	5 days	Dst index
L=3.2	5 days	Dst index
L=3.4	2 days	Dst index
L=3.6	2 days	Dst index
L=3.8	2 days	Dst index
L=4.0	2 days	Dst index
L=4.2	2 days	Dst index + GEO flux
L=4.4	2 days	Dst index + GEO flux
L=4.6	2 days	Dst index + GEO flux
L=4.8	2 days	Dst index + solar wind speed + GEO flux
L=5.0	2 days	Dst index + solar wind speed + GEO flux
L=5.2	2 days	Dst index + solar wind speed + GEO flux
L=5.4	8 days	Dst index + solar wind speed
L=5.6	2 days	Dst index + solar wind speed + solar wind pressure
L=5.8	2 days	Dst index + solar wind speed + solar wind pressure

GEO (6.6 RE)	3 days	Kp index + solar wind speed + solar wind pressure

Discussion about input parameter transition by L values

- The **Dst** index is the best overall single parameter for predicting at **3 ≦ L ≦ 6**, while for the **GEO** flux prediction, the **Kp** index is better than Dst.

- The **V_{SW}** parameter is effective for the models at **L≧4.8** only. This might be related to the inner edge of particle acceleration by ULF waves, a role of inward radial diffusion to lower L shells, the average, location of the plasmapause and the role of local acceleration by electrons interacting with whistler mode chorus outside of the plasmasphere.

- The **P_{SW}** parameter is effective for the models at **L≧5.6** only. The boundary seems to be related to MeV electron loss owing to magnetopause shadowing. (statistical threshold from September 2012 to December 2013).

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L-time diagram prediction of the outer radiation belt

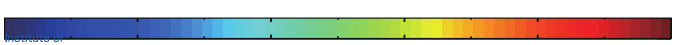
The model successfully predicts the timing and location of the flux maximum as much as 2 days in advance and that the electron flux decreases faster with time at higher L values, both model features consistent with the actual observed behavior.

Observation

(VAP/REPT-A 2.3 MeV electrons)

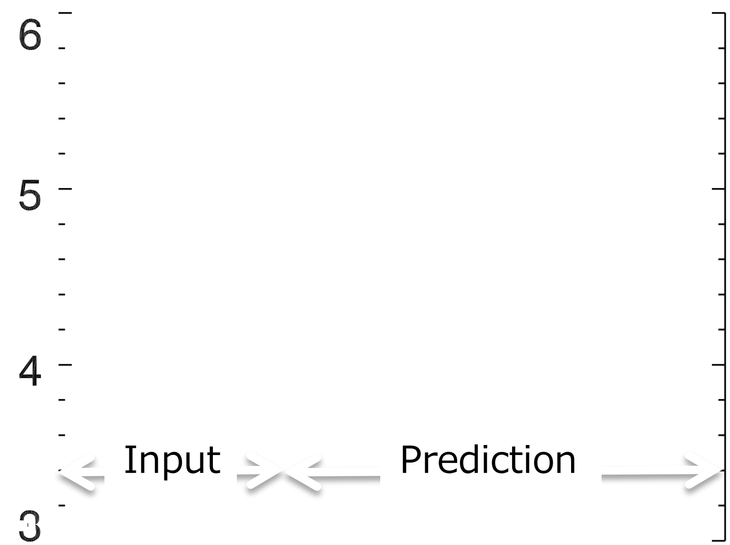
days

Observed flux log10(/cm2 sr s MeV)



Kalman Prediction

(over 10 days after day=0: 131)



days

Predicted flux log10(/cm2 sr s MeV)

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Summary

- We have developed prediction models of MeV electron flux in the outer radiation belt using energetic particle data from GOES, HIMAWARI, and Van Allen Probes. These models are based on multivariate AR analysis and and Kalman filter [Sakaguchi et al., *Space Weather*, 2013, 2015]. These models also give us some clue for understanding RB dynamics.
- GEO MeV electron flux data from the Japanese HIMAWAEI-8 metrological satellite is available for the real-time monitoring since November 2014. Data will be provided from NICT soon.

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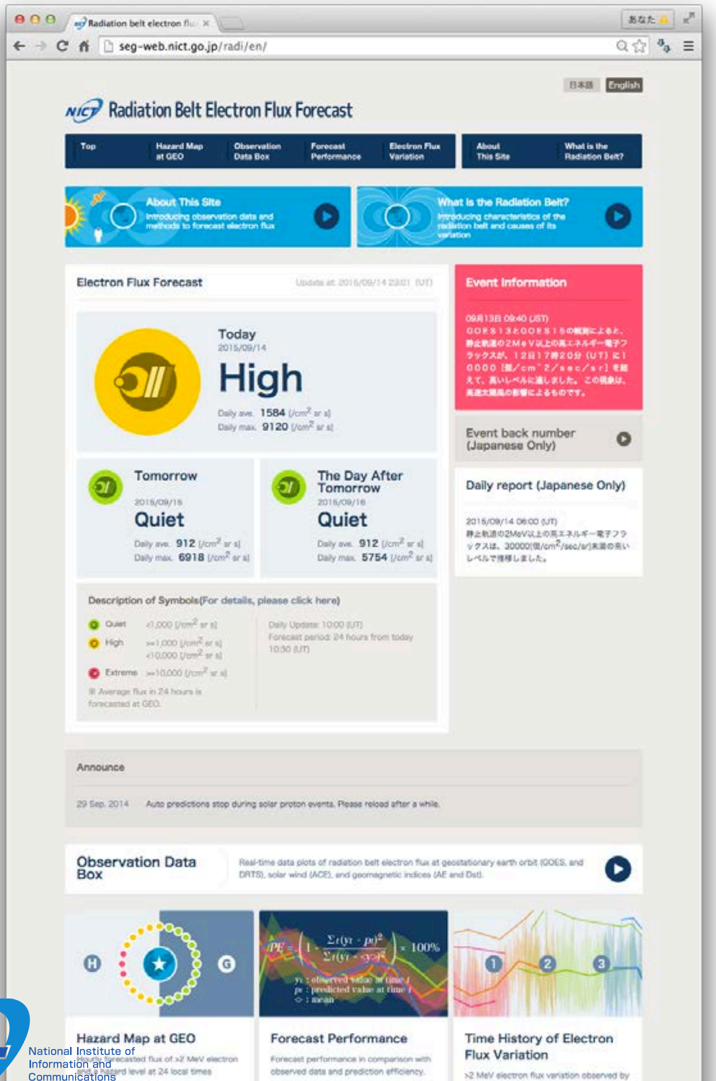
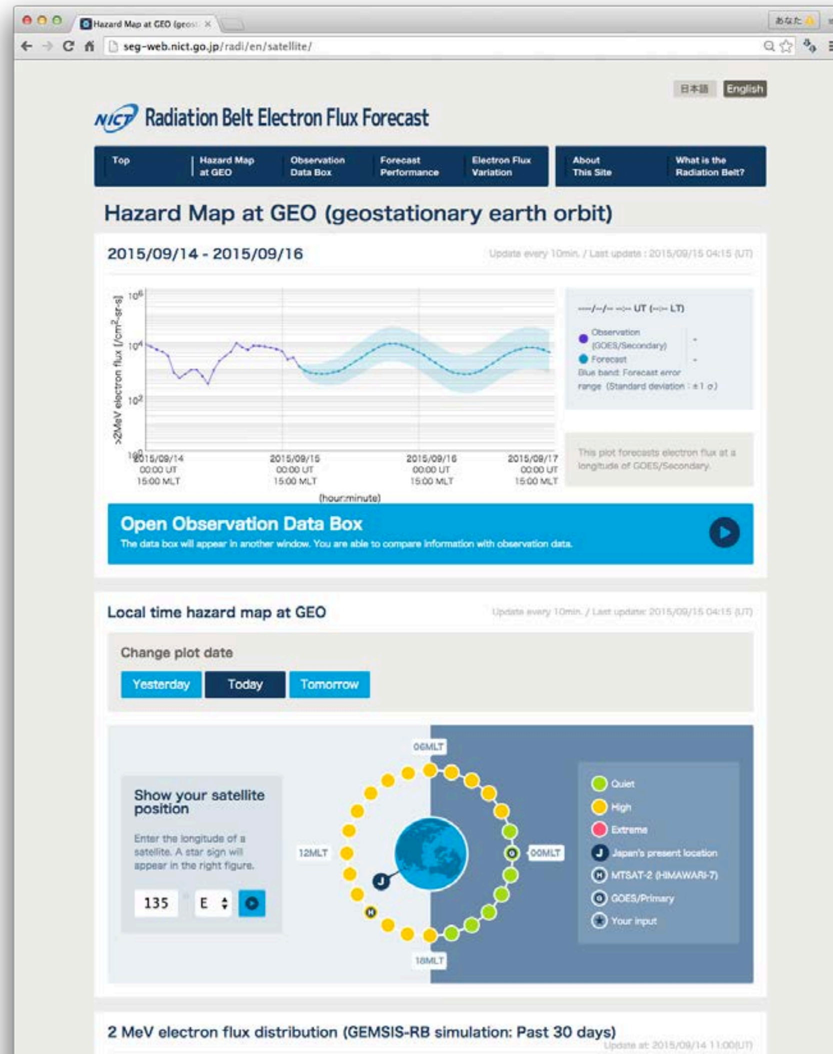
Radiation Belt Electron Forecast Web

http://seg-web.nict.go.jp/radi/en/





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Thank you for attention