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# Solar flare forecasting verification in RWC Japan and opportunities for partnership with CCMC

8th CCMC Workshop @ Annapolis on 11 – 15 April 2016

# Outlines

- Operational space weather forecast in Regional Warning Center (RWC) Japan and solar flare forecast verification study
- Possibility to join flare scoreboard and newly developing flare forecasting model
- Possibility of cooperation of the other model validation efforts

# OPERATIONAL SPACE WEATHER FORECAST IN RWC JAPAN AND SOLAR FLARE FORECAST VERIFICATION STUDY

# NICT is …

- Only one operational space weather forecast agency in Japan.
- Responsible for issuing space weather forecasts every day.
- One of a Regional Warning Center in ISES.

# Regional Warning Center (RWC) in International Space Environment Service (ISES)

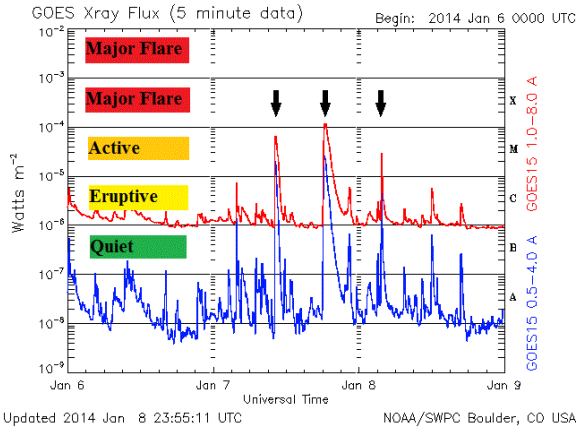

Some RWC, especially old member of ISES, has exchanged information of forecast of solar flares, geomagnetic disturbances, and proton events.

[Present Space Weather Forecast from ISES]

| | | |
|---|---|---|
| Tokyo [Japan] (1500JST) | Flare forecast on 29(1days) | Quiet |
| | Magnetic forecast on 29(1days) | Active condition expected |
| | Proton forecast on 29(/days) | Quiet |
| Beijing [China] (1530JST) | Flare forecast on 29(2days) | Quiet |
| | Magnetic forecast on 29(2days) | Quiet |
| | Proton forecast on 29(2days) | Quiet |
| Brussels [Belgium] (2010JST) | Flare forecast on 29(2days) | Quiet |
| | Magnetic forecast on 29(2days) | Quiet |
| | Proton forecast on 29(2days) | Quiet |
| Sydney [Australia] (0900JST) | Flare forecast on 30(1days) | Quiet |
| | Magnetic forecast on 30(2days) | Quiet |
| | Proton forecast on 30(2days) | Quiet |
| Jeju [Republic of Korea] (1100JST) | Flare forecast on 29(1days) | Quiet |
| | Magnetic forecast on 29(1days) | Quiet |
| | Proton forecast on 29(1days) | Quiet |
| Boulder [USA] (1230JST) | Flare forecast on 29(1days) | Quiet |
| | Magnetic forecast on 29(1days) | Active condition expected |
| | Proton forecast on 29(1days) | Quiet |

# Operational solar flare forecast defined by ISES

| Ursigram code (UGEOA) | Solar flare forecast | Maximum flare class within 24 hours from forecast issue time | Maximum x-ray flux of 1-8Å within 24 hours from forecast issue time |
|---|---|---|---|
| 0 | Quiet | A or B class | $Fx < 10^{-6}$ W m$^{-2}$ |
| 1 | Eruptive | C class | $10^{-6} \leqq Fx < 10^{-5}$ W m$^{-2}$ |
| 2 | Active | M class | $10^{-5} \leqq Fx < 10^{-4}$ W m$^{-2}$ |
| 3 | Major Flare | X class | $10^{-4} \leqq Fx$ W m$^{-2}$ |




| Country | Forecast issue time |
|---|---|
| Sydney, Australia | 00:00 UT |
| Jeju, Korea | 02:00 UT |
| Boulder, US | 03:30 UT |
| Tokyo, Japan | 06:00 UT |
| Beijing, China | 06:30 UT |
| Brussels, Belgium | 11:10 UT |

# Operational solar flare forecast in RWC Japan

- Started in 1992, and continues up to now.
- Issued once a day at 06:00 UT for 365days/year
- 4-categoly deterministic forecast for flare class

# Data set of forecast-observation pair

We use data of forecast-observation pair for 16 years (2000 to 2015 = 5844 days) in this verification study.

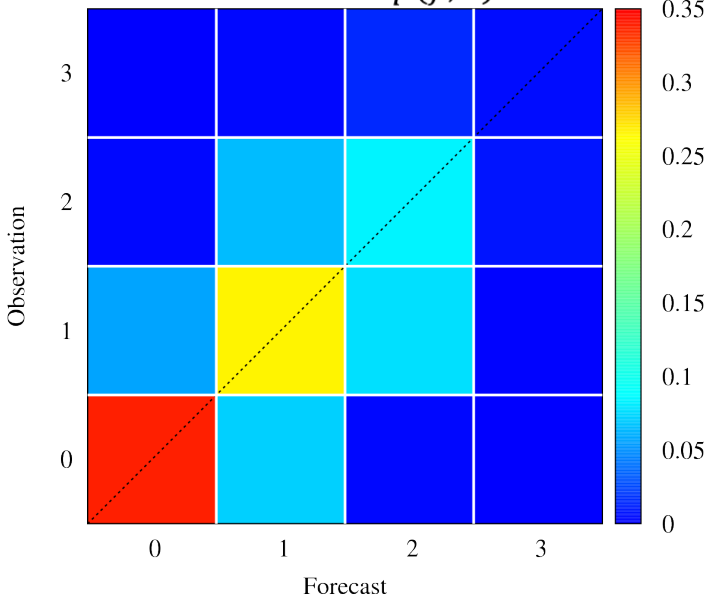
| OBSERVATION (UGEOA code) | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| 3 | 0 | 19 | 82 | 29 |
| 2 | 23 | 379 | 495 | 43 |
| 1 | 335 | 1554 | 453 | 11 |
| 0 | 1979 | 419 | 21 | 2 |
| # of days | FORECAST (UGEOA code) | | | |

Contingency table for our solar flare forecast for 16 years data.

# Joint PDF and marginal PDF

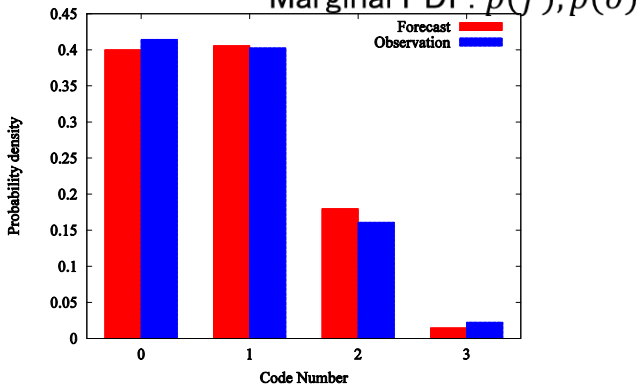
In forecast verification study, the contingency table is regarded as a joint probability density function (PDF) $p(f, o)$. (Murphy & Winkler 1987)

Joint PDF: $p(f, o)$




A good association is appeared.

Marginal PDF: $p(f), p(o)$

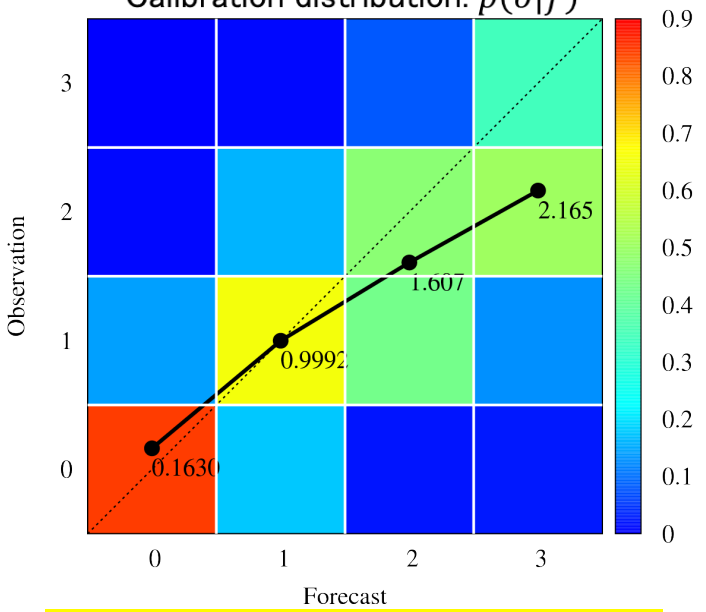



In view from marginal distribution, forecast–observation pair is almost unbiased.

# Factorization of joint PDF

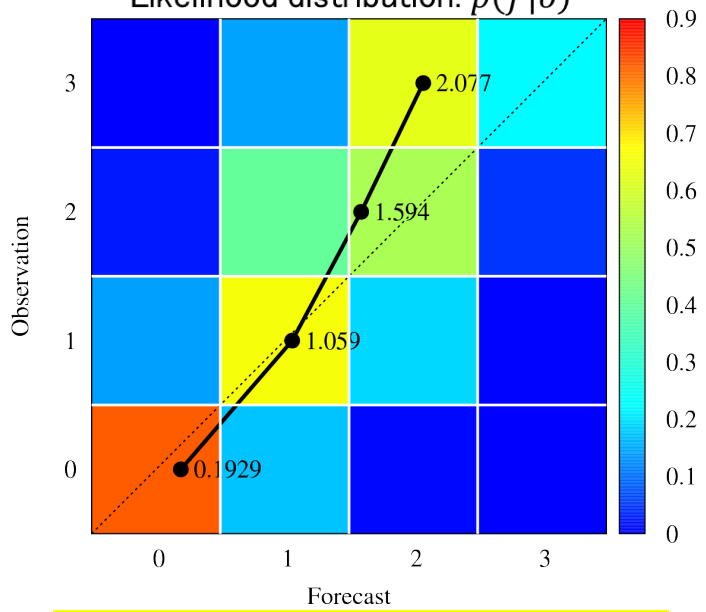
Factorization of joint PDF: $p(f,o) = p(o|f) \cdot p(f) = p(f|o) \cdot p(o)$

Calibration distribution: $p(o|f)$




X-class was "not" the most frequently occurred when X-class had been forecasted.

Likelihood distribution: $p(f|o)$




X-class had "not" the most frequently been forecasted when X-class was occurred.

Technology NICT

# Conventional scalar performance measures

- Most of conventional scalar performance measures are defined only for dichotomous forecasts.
- Because our operational solar flare forecasts are multi-categorical forecasts, the contingency table must be collapsed to dichotomous forecasts when the conventional scalar performance measures are calculated.
- Define, for example, flare class is more than or equal to M class as events, and less than M class as no events.

Collapsed contingency table for M≤ as events.

| | | | |
|---|---|---|---|
| OBSERVATION | E | 421 | 649 |
| | N | 4287 | 487 |
| # of days | | N | E |
| | | FORECAST | |

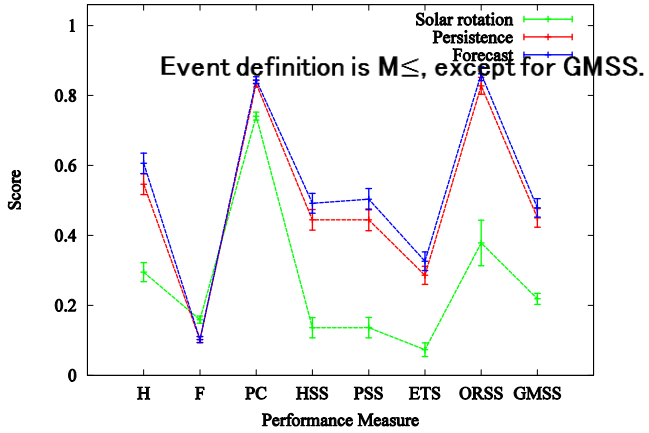
Because of 3 degrees of freedom of the contingency table, at least 3 scores are required to completely describe these forecast performance.

- $base\ rate: p = 0.183 \pm 0.00991$
- $Hit\ rate: F = 0.606 \pm 0.0292$
- $False\ alerm\ rate: F = 0.102 \pm 0.00859$
- $Proportion\ correct: PC = 0.844 \pm 0.00929$
- $Heidke\ skill\ score: HSS = 0.492 \pm 0.0283$
- $Pierce\ skill\ score: PSS = 0.504 \pm 0.0305$
- $Equitable\ threat\ score: ETS = 0.326 \pm 0.0265$
- $Odd\ ratio\ skill\ score: ORSS = 0.862 \pm 0.0198$
- $Bias: B = 1.06 \pm 0.0568$

The 95% confidence intervals are calculated by using score confidence interval (Agresti & Brent; 1998) and error propagation rule.

# Comparison with three forecast methods

- Forecast: our operational forecast.
- Persistence: today's forecast is the same as yesterday's observation.
- Solar rotation: today's forecast is the same as observation on 27 days ago.




All scores for our operational forecast are better than solar rotation and persistence methods (false alerm rate F is negative orientation measure).
However, a difference between forecast and persistence is not so large, and 95% confidence intervals are overlapped.

# Multi-categorical equitable skill score

- Collapsing a multi-categorical forecast to a dichotomous forecast causes some information losses, which are included in joint PDF of forecast-observation pairs.
- Gandin & Murphy (1992) proposed equitable skill score for multi-categorical forecast-observation case (GMSS).
- We applied the closed form of GMSS (Gerrity; 1992) to our 4-category operational solar flare forecast.

- $GMSS = Tr(\mathbf{S} \cdot \mathbf{T})$
- $\mathbf{S}$: *Score matrix*
- $\mathbf{T}$: *Contingency table*
- Score matrix is defined as satisfying equitability.

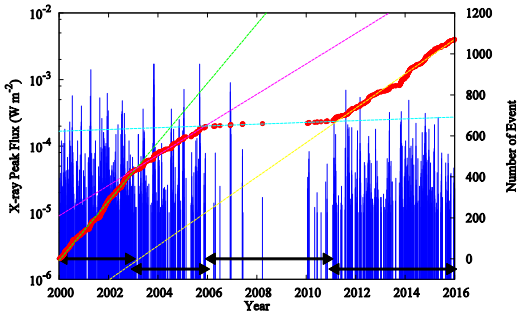
***Gandin – Murphy skill score*: *GMSS***

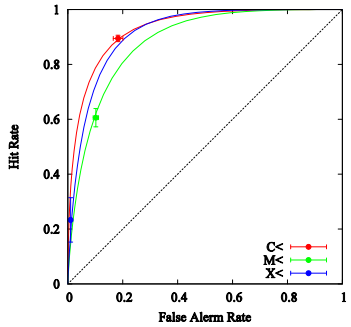
- $\boldsymbol{GMSS(Forecast) = 0.479 \pm 0.0265}$
- $\boldsymbol{GMSS(Persistence) = 0.450 \pm 0.0266}$
- $\boldsymbol{GMSS(Solar\ rotation) = 0.219 \pm 0.0157}$

Our operational forecast is better than solar rotation and persistence methods.
However, a difference between forecast and persistence is not so large, and the 95% confidence interval is overlapped.

# Other analyses (omitted from this presentation)

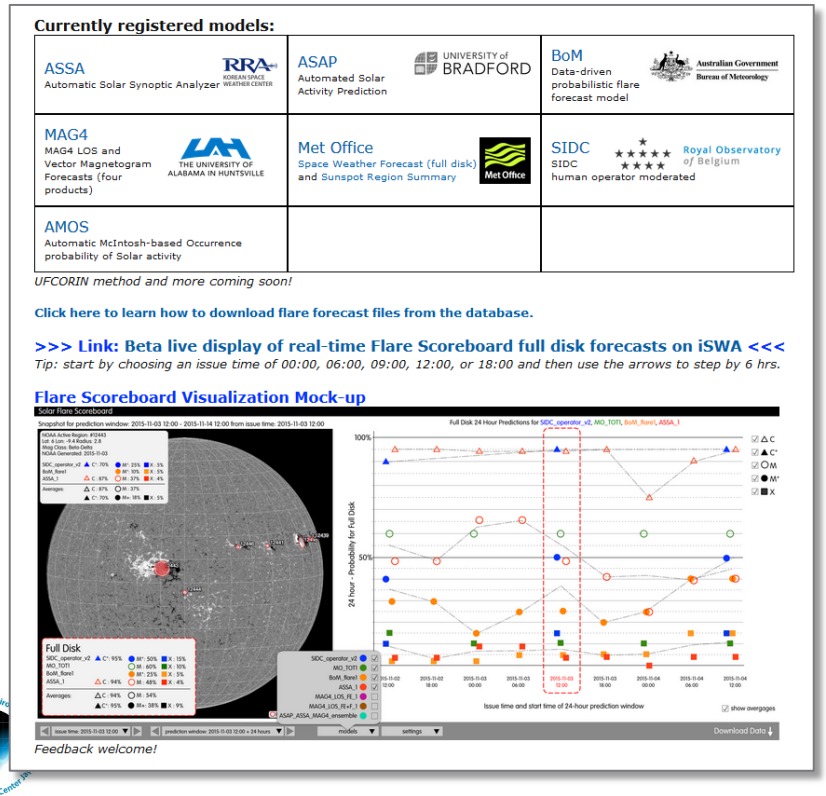
- Analyses for other event definitions.
- Analyses for subset data defined by solar activity.
- ROC and ROL analyses.
- Other…



# POSSIBILITY TO JOIN FLARE SCOREBOARD AND NEWLY DEVELOPING FLARE FORECASTING MODEL

# Possibility to join flare scoreboard



**Currently registered models:**

| | | |
|---|---|---|
| **ASSA**<br>Automatic Solar Synoptic Analyzer | **ASAP**<br>Automated Solar Activity Prediction | **BoM**<br>Data-driven probabilistic flare forecast model |
| **MAG4**<br>MAG4 LOS and Vector Magnetogram Forecasts (four products) | **Met Office**<br>Space Weather Forecast (full disk) and Sunspot Region Summary | **SIDC**<br>SIDC human operator moderated |
| **AMOS**<br>Automatic McIntosh-based Occurrence probability of Solar activity | | |

*UFCORIN method and more coming soon!*

**Click here to learn how to download flare forecast files from the database.**

**>>> Link: Beta live display of real-time Flare Scoreboard full disk forecasts on iSWA <<<**

*Tip: start by choosing an issue time of 00:00, 06:00, 09:00, 12:00, or 18:00 and then use the arrows to step by 6 hrs.*

**Flare Scoreboard Visualization Mock-up**

*Feedback welcome!*

- Flare scoreboard is designed for probabilistic flare forecasts.
- Our "issued" flare forecast is not probabilistic but deterministic forecast.

## Two choices to join the flare scoreboard.

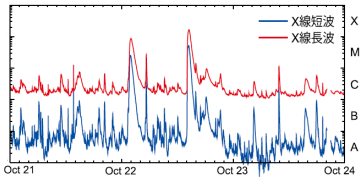
1. Setup a deterministic forecast option in flare scoreboard.

2. We estimate flare probabilities.
   - We have estimated flare probabilities once a day as a reference data to make decision by forecaster.
   - The method is very simple, which uses statistics of historical flare occurrence data and NOAA's SRS report.
   - New flare forecast model has been developing.

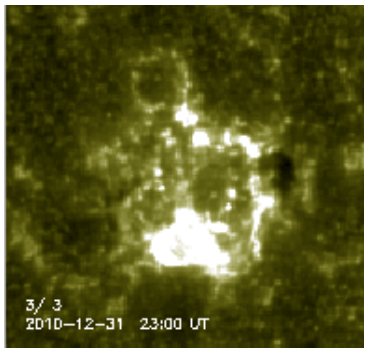
# New flare forecast model

Flare Forecast using Machine-learning in NICT

Used data

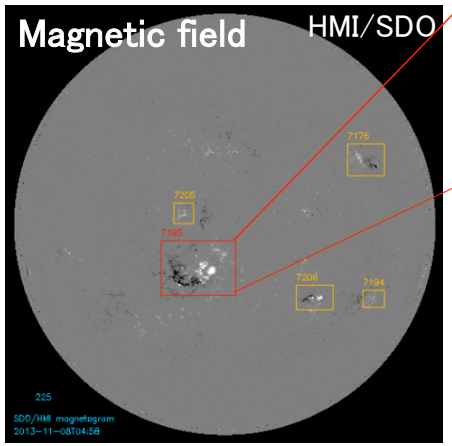


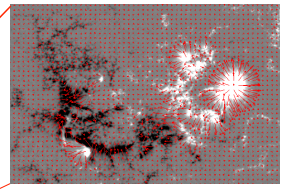

GOES X-ray



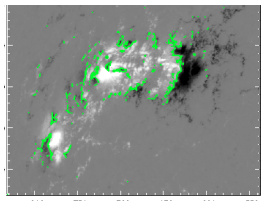

Chromospheric bright point (preflare)

$3 \times 10^5$ images & 50 features
during 2010-2015, taken by SDO.



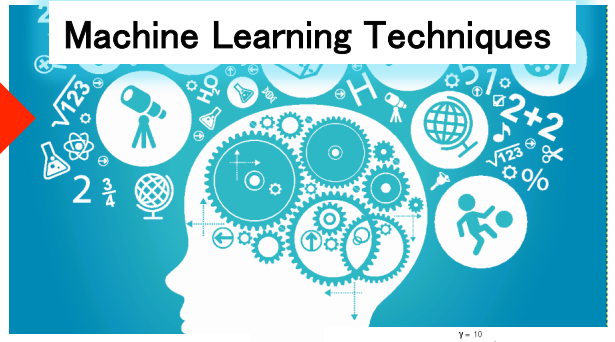
Vector Magnetic fields

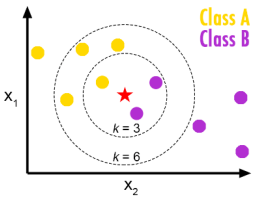


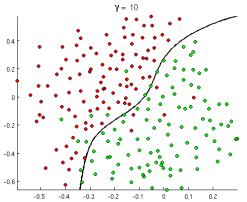
Neutral lines

Input

Machine Learning Techniques





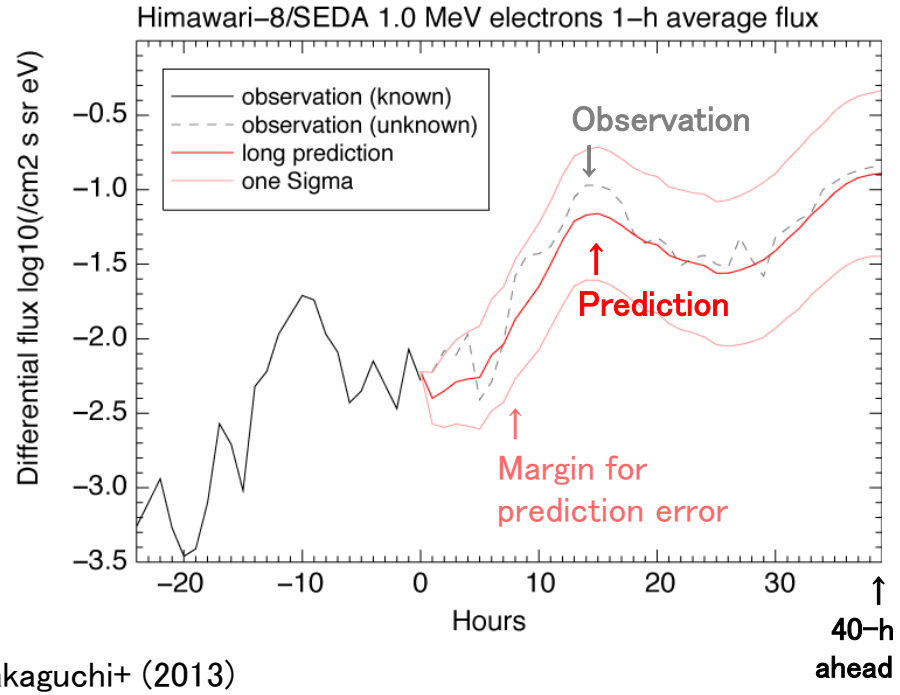
RWC Japan: TSS～0.5
↓
Machine Learning: TSS～0.79

Nishizuka+ (2016) in preparation

# POSSIBILITY OF COOPERATION OF THE OTHER MODEL VALIDATION EFFORTS

# Radiation belt electron forecast model

## 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

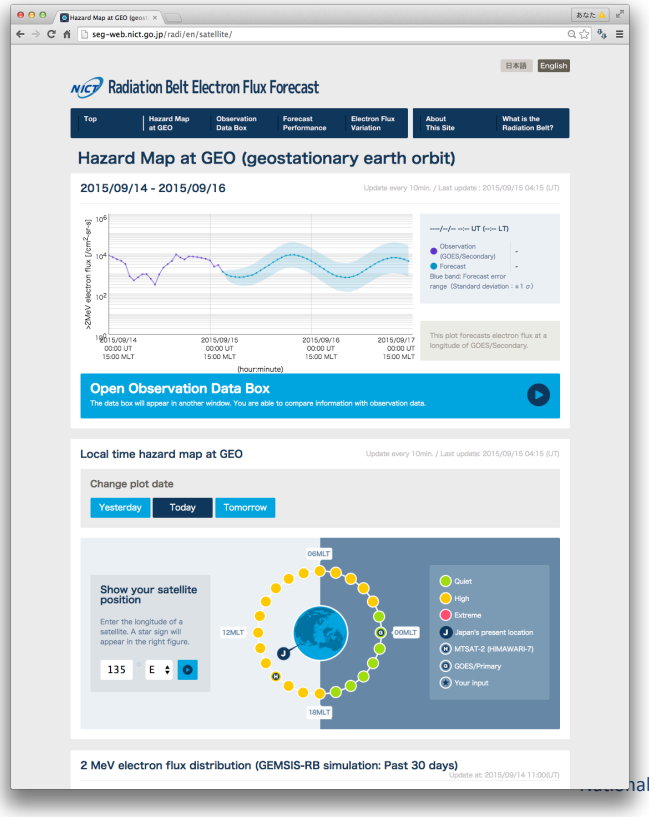
— Solar wind pressure

— Dst index

#Coefficient matrix A is estimated by the least square method

Sakaguchi+ (2013)

# Radiation belt electron forecast operation


This model is already in operation.

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

Thank you