# Case Study Results of AI-based Space Weather Forecast Models Using Satellite Data

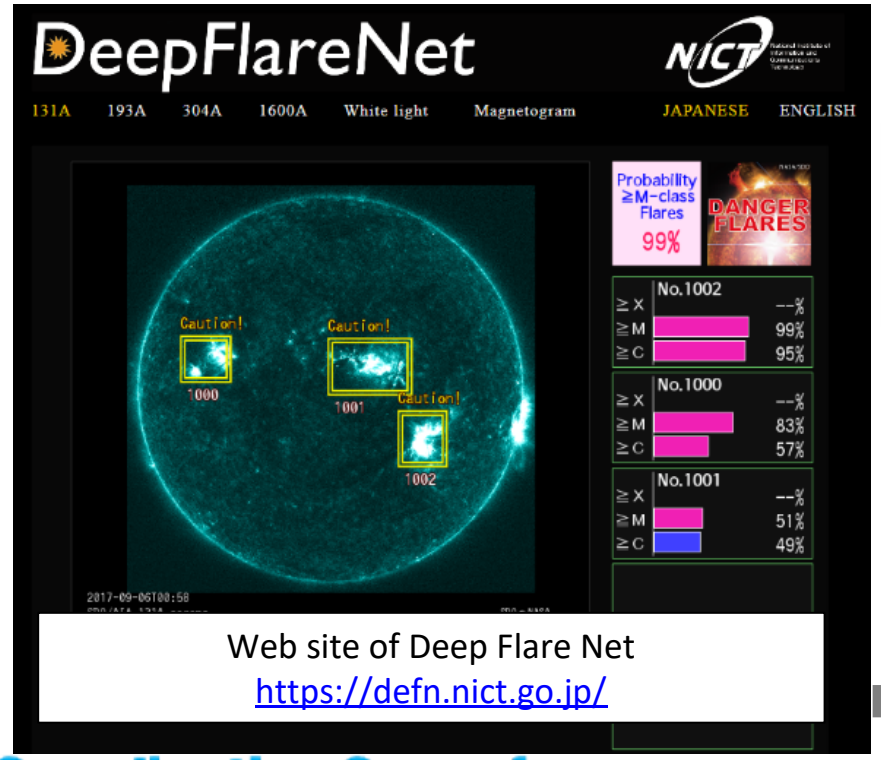
Presented to CGMS-53 Plenary session, agenda item 6

Coordination Group for Meteorological Satellites

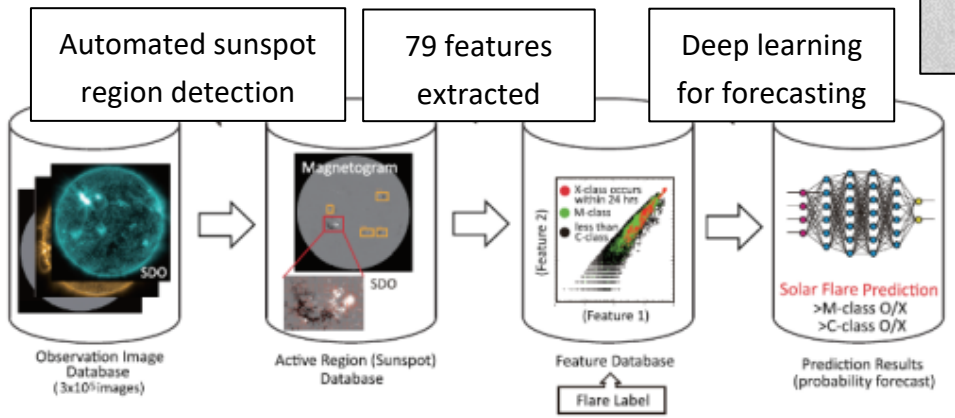
# Solar Flare Prediction using Deep Learning (Deep Flare Net)

**World's first operational solar flare forecast system using deep learning** (Launched April 5, 2019, 6 years in operation)

- Improving performance with TSS as the evaluation metric.
- Enables the classification and prediction of complex data, beyond human ability.
- Accuracy evaluation conducted using operational real-time SWx data




Web site of Deep Flare Net
https://defn.nict.go.jp/

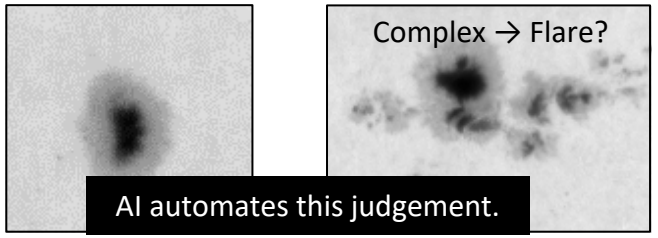


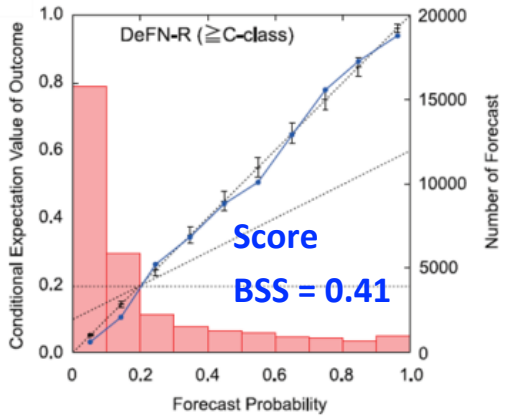

- Inputs: Either solar images or physical features.
- Training data: 300,000 solar images (4k x 4k) from the past 6 years.
- Daily satellite data: Over 1.5 TB

**Executing deterministic, probabilistic, and regression predictions.**

**Solar Image data at GEO (SDO)**

**Human visual judgment: Checks sunspot complexity.**




**Reference**


- NICT研究報告、宇宙環境計測・予測技術特集、vol.67, No. 1, 2021, 4章 太陽・太陽風研究, 4-3節 太陽フレア発生予測
- Nishizuka et al., ApJ, 2017
- Nishizuka et al., ApJ, 2018
- Nishizuka et al., EPS, 2021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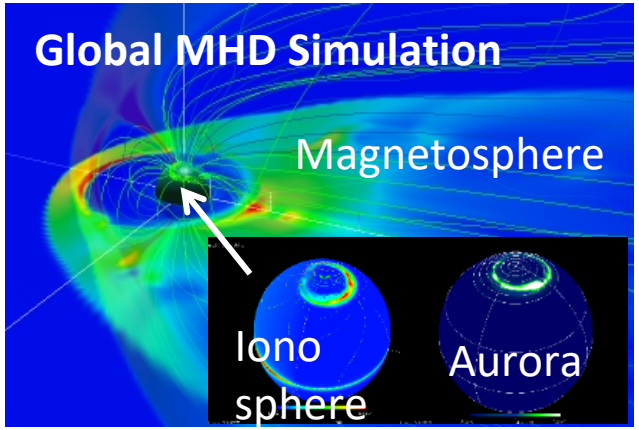
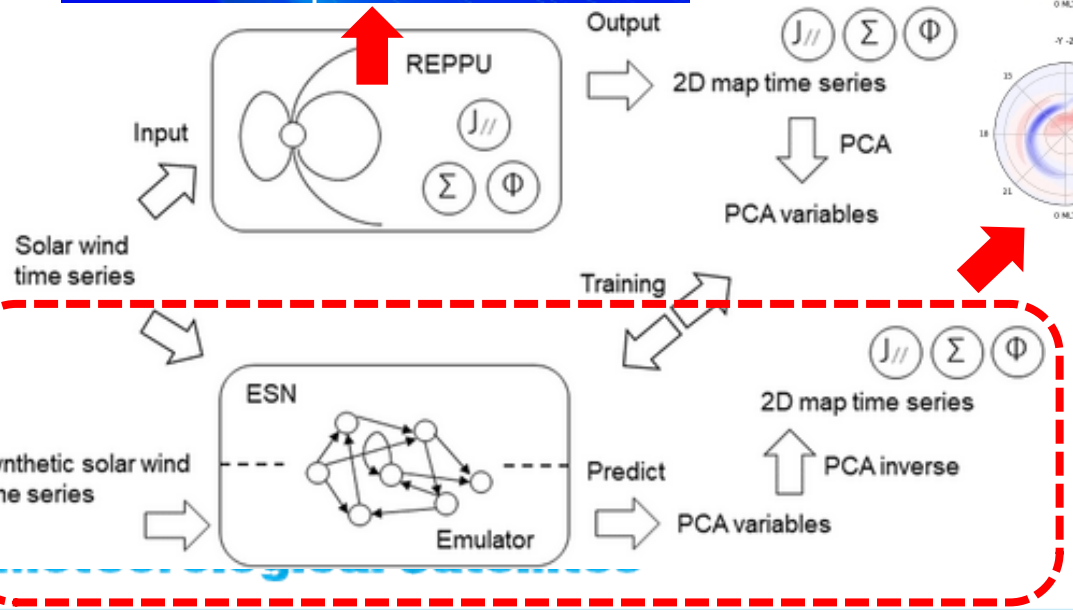
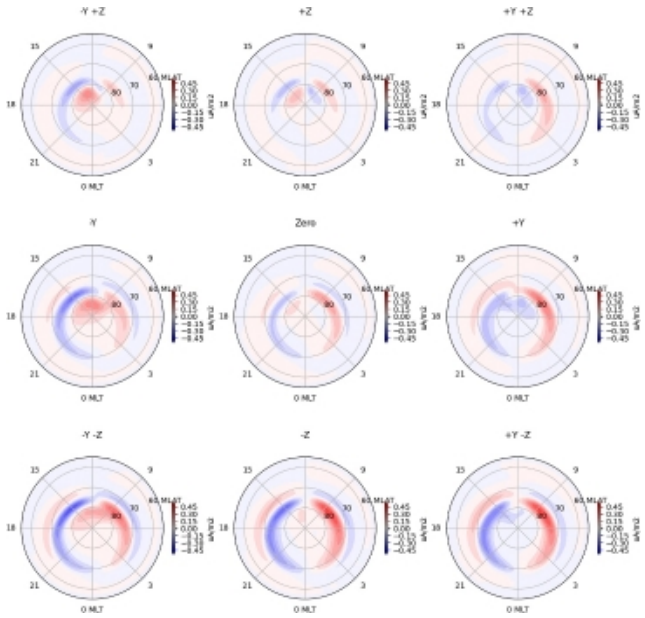
Patent: No. 7199075 "Prediction System and Prediction Method" (Japanese Patent Application No. 2018-090085)

# Ultra-Fast Computation of 2D Auroral Current System using an ML-based Emulator

- Machine learning-based emulator capable of ultra-fast computation of 2D auroral current systems using solar wind data
- Training data is from archive of real-time global MHD simulation outputs of the geospace environment
- **Applications:** space weather ensemble forecasting, aurora prediction, satellite charging estimation, and more



**IMF clock angle dependence of 2D distributions of field-aligned currents (Emulator Outputs)**

**Solar wind data at L1 (ACE/DSCOVR)**

## Challenges with Conventional Models

High-performance computing systems are required to run global MHD simulation.

## Our Solution: ML-based Emulator

We developed an emulator trained on the relationship between solar wind input and simulation results (response).

→ **This enables aurora prediction to be approximately one million times faster than physical models, using significantly fewer resources.**

**Reference**

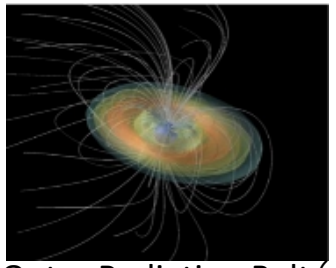
- Kataoka, R., Nakamizo, A., Nakano, S., & Fujita, S. (2024). Machine learning-based emulator for the physics-based simulation of auroral current system. *Space Weather*, 22, e2023SW003720.

# Probabilistic Forecast of High-Energy Electron Fluence Levels using Deep Learning

## Deep Learning Model for Probabilistic Forecasting of High-Energy Electron Fluence Levels at GEO

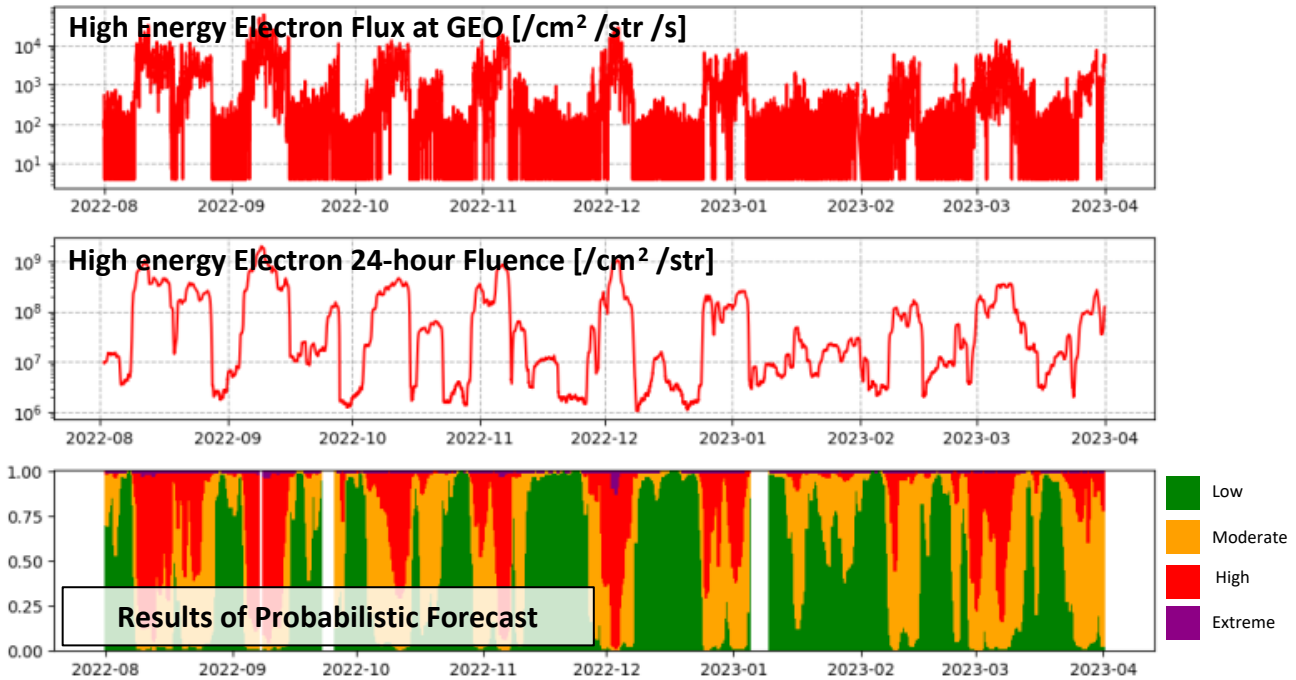
**RadeAI (Radiation belt electrons – A.I.)**

**High energy electron at GEO (GOES)**

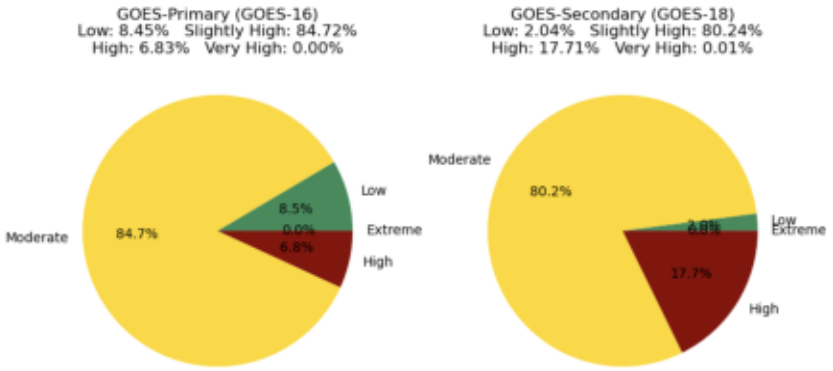


Outer Radiation Belt（https://radi.nict.go.jp/radio/）

- High-energy electrons in space can impact satellite electronics, leading to malfunctions and failures.
- Predicts the probability of 24-hour high-energy electron fluence levels in geostationary orbit across four distinct levels.




Probabilistic Forecast of 24-Hour High-Energy Electron Fluence Levels by RadeAI

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# Introducing of AI/ML into space weather forecasting operation

- **Space weather forecasting is well-suited for the introduction of AI/ML**
  - Since the flow of energy and materials is primarily unidirectional (The Sun → Solar Wind → Magnetosphere → Ionosphere (Note: Coupling processes exist within Geospace)), making it easier for AI/ML to learn the cause and effect.
  - While both ground-based SWx observations and space-based ones (especially *in-situ* space-based observations) are sparser compared to terrestrial weather observations, some degrees of meaningful outputs can still be derived from AI/ML-based models.
  - The importance of upstream space-based observations (*e.g.* solar and solar wind observations from L1, L5, and L4) is increasing.
- **Collaboration with AI/ML Technology Researchers**
  - Efficient model and product development through the fusion of specialized knowledge in space weather research and AI/ML research
- **Utilization as a tool of operational forecasting**
  - Final forecast decisions are made by human experts. AI/ML results serve as reference information for forecasters.

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