10-14 June, 2024
UN/Germany Workshop on the International Space Weather Initiative:
Preparing for the Solar maximum

RECENT JAPANESE ACTIVITIES FOR OPERATIONAL SPACE WEATHER SERVICES

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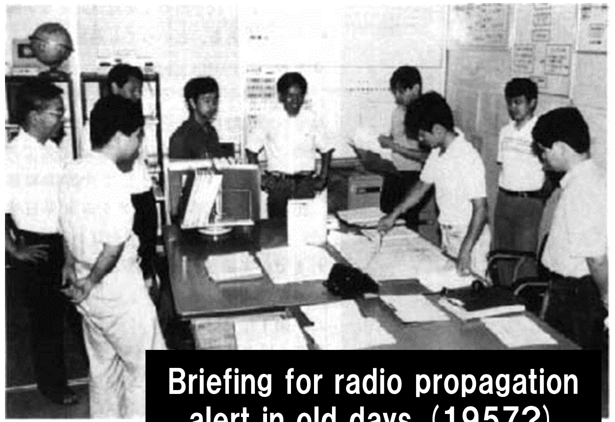
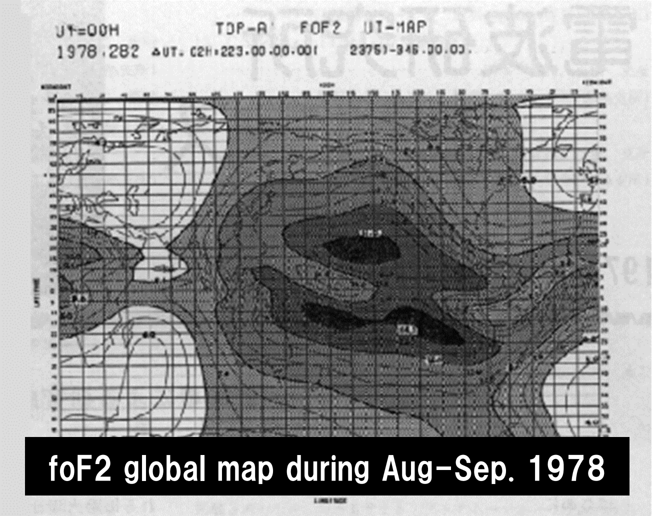
- Recent Japanese activities for operational space weather services
- A brief report of 2024 May event
- New alert criteria considering social impact

Introduction: NICT Space Weather Operation

Solar radio spectrum antenna (70-500MHz)



Briefing for radio propagation alert in old days (1957?)



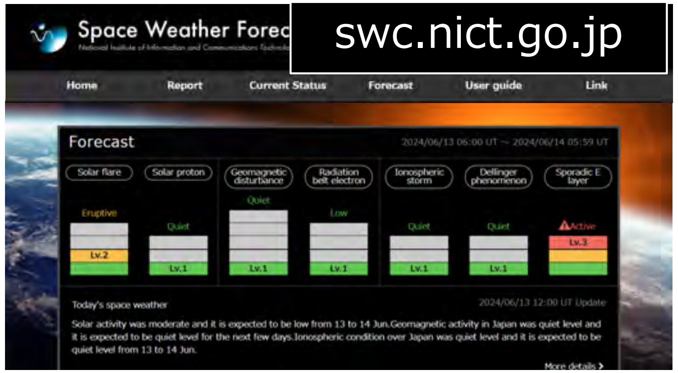
foF2 global map during Aug-Sep. 1978

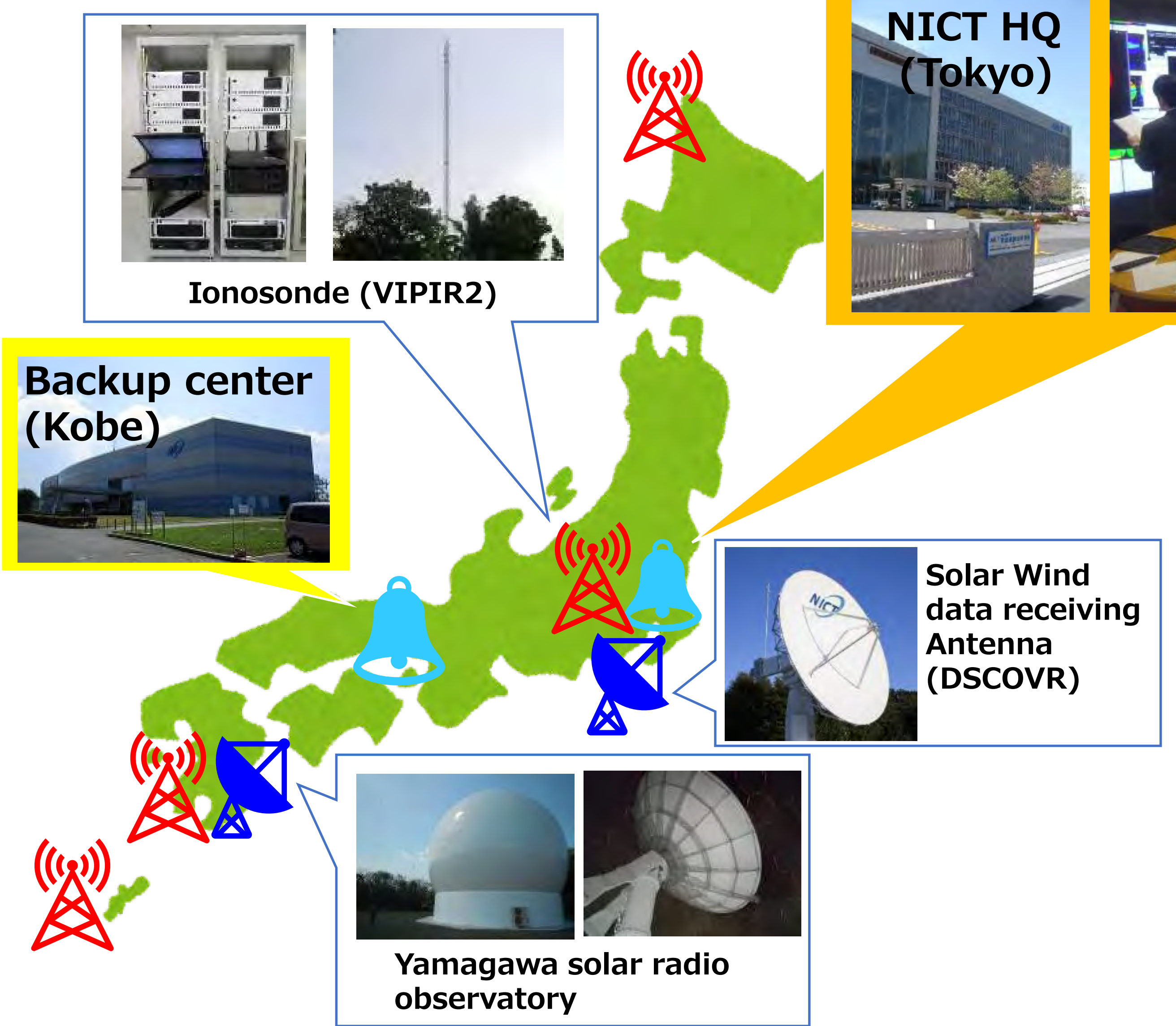
ISS-b "Ume-2" satellite

- Since 1952, NICT have operationally measured solar radio spectrum, and started operational alert service for radio propagation since 1957.
- NICT has been providing Space Weather nowcast and forecast information.

NICT Space Weather Forecast Center
https://swc.nict.go.jp

Current NICT Space Weather Operation





Services

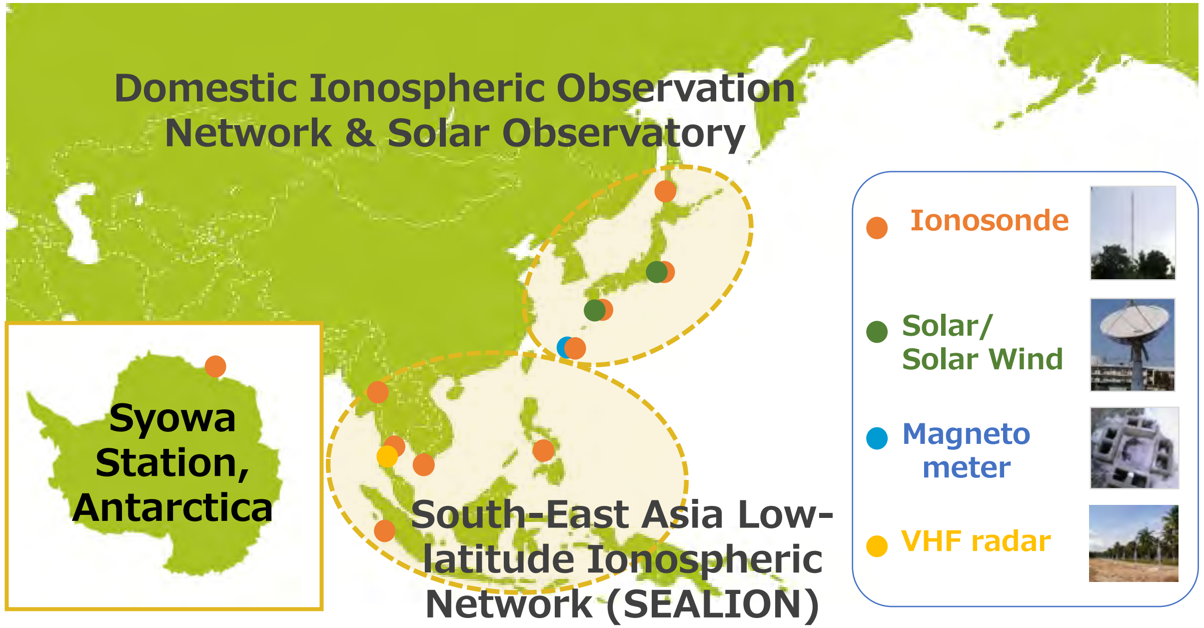
- Domestic users: satellite operator, aviation office and companies, power supplier, HF telecommunicator/broadcaster, GNSS service provider/user, resource survey, Univ. and research institutes, amateur HF operators, etc.
- E-mail subscribers:7000, Web access: 70,000/month, SNS (Facebook, X)

Recent activities

- ICAO service in (since Nov. 7, 2019)
- 24/7 operation (since Dec. 1, 2019)

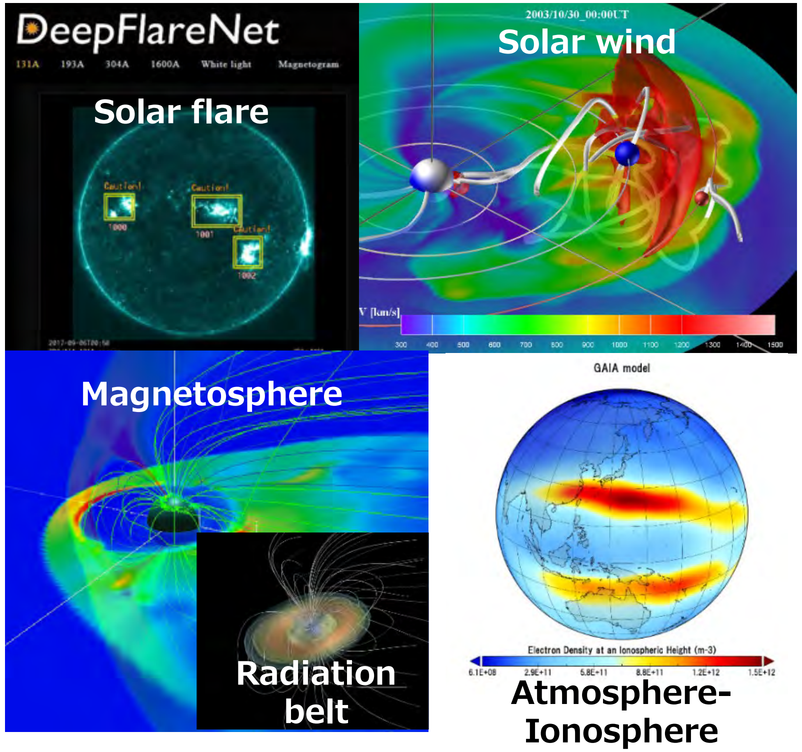
Current R&D Activities

Space Weather Observation Network



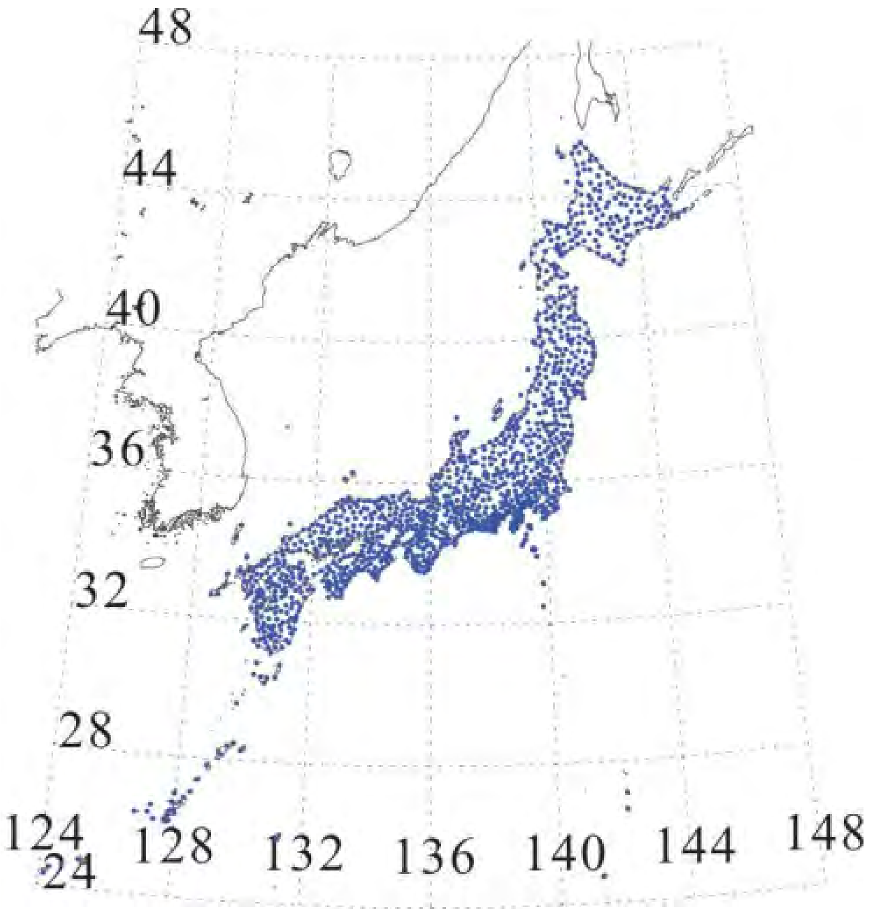
- We have developed ground-based observation technologies and networks to monitor space weather phenomena through international collaboration.

Space Weather Forecast Models

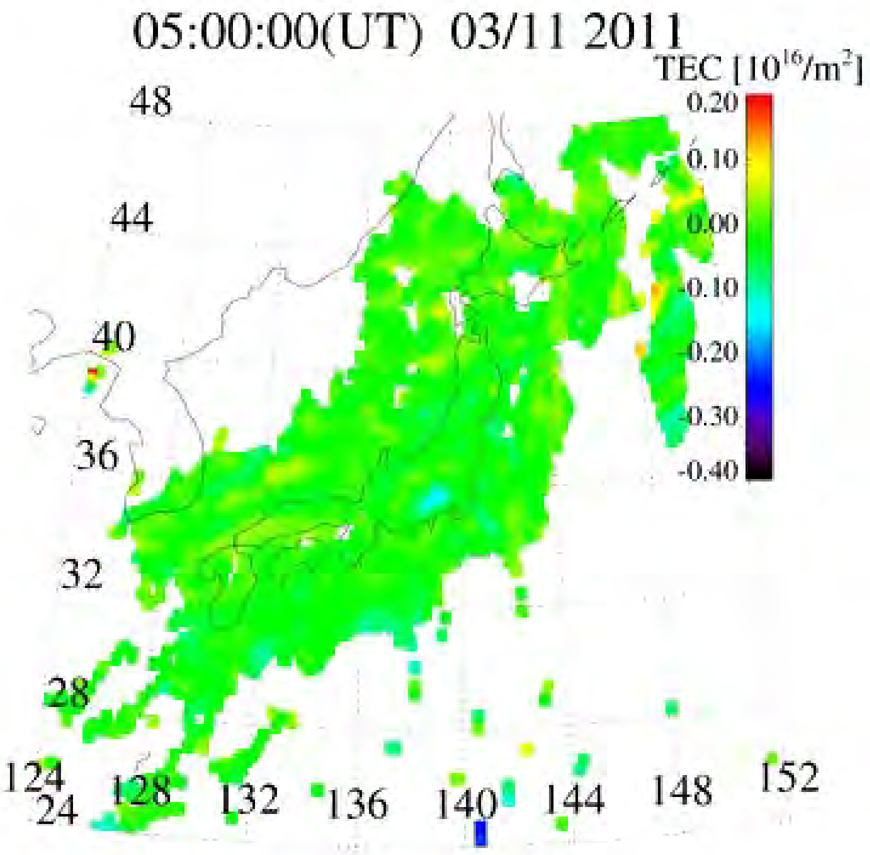


- We have developed forecast models of space weather phenomena using numerical simulation, data assimilation, and AI technologies.

Current R&D Activities



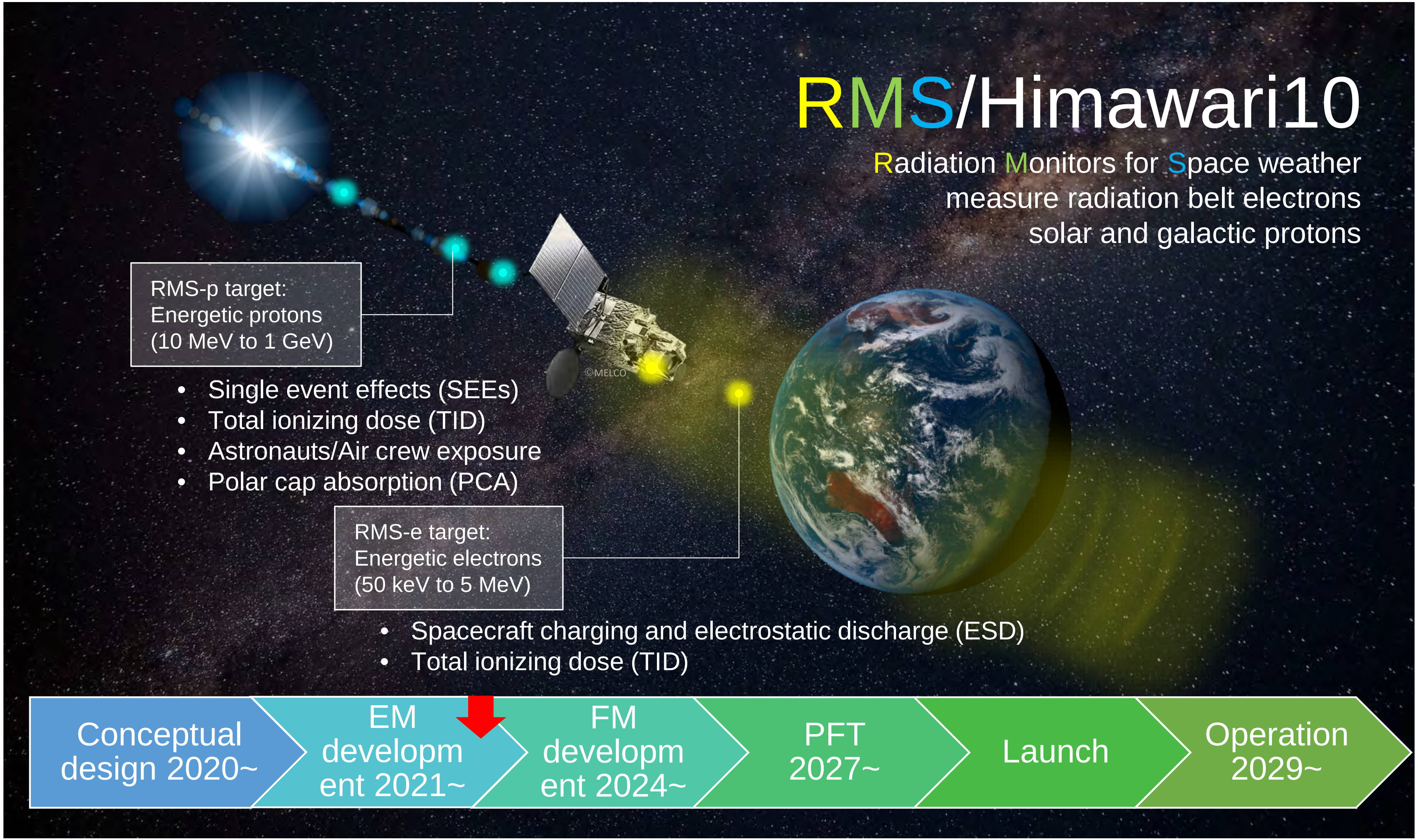
Distribution of GNSS receivers of GEONET (~1,300 stations)



TEC variation map at Tohoku earthquake. The red star represents the epicenter. [Tsugawa et al., EPS, 2011].

- We developed an operational TEC observation system with high temporal and spatial resolution (30sec, 0.15x0.15 deg) using ~1300 GNSS stations in Japan.

High energy particle sensors aboard Himawari 10



High energy particle sensors aboard Himawari 10

Targets

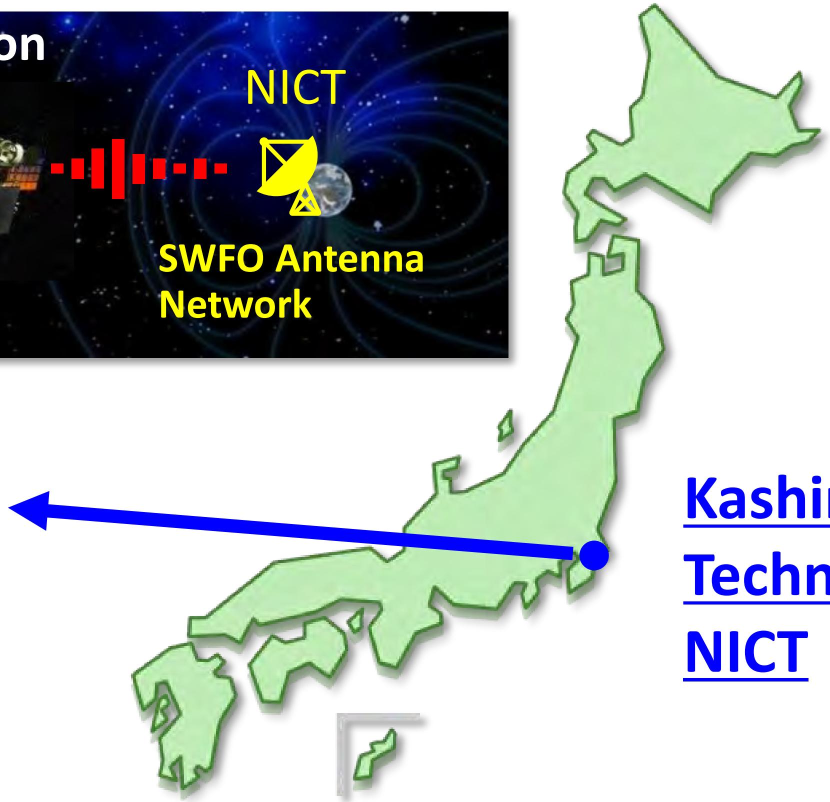
- Electrons in the outer radiation belt (Van Allen belt)
- Protons in solar energetic particles and galactic cosmic ray

Missions

- High-energy particles that cause spacecraft malfunctions and degradations (ESD, SEEs, and TID), HF communication failure in the polar regions due to PCA, and space radiation exposure (polar aircraft and space activities); are monitored, for the purpose of nowcasting, forecasting, and warnings to space weather users.

	RMS-e(lo)	RMS-e(hi)	RMS-p(lo)	RMS-p(hi)
Particle	electron		proton	
Energy range	50–1300 keV	0.8–6, >2 MeV	10–500 MeV	320–1000 MeV
Energy resolution	< 20%	< 10%	< 20%	–
Energy channels	8 diff. flux	7 diff. flux 1 integral flux	12 diff. flux	3 diff. flux 1 integral flux
Field of view	±20 deg.	±20 deg.	±20 deg.	±20 deg.
Viewing direction	1: West 2: North	1: West 2: North	1: West	1: West
G-factor	0.0005 cm^2 sr	0.1 cm^2 sr	0.2 cm^2 sr	0.3 cm^2 sr
Time resolution	1 sec.			
Detector	SSD			Cherenkov

Ground station of SWFO Antenna Network

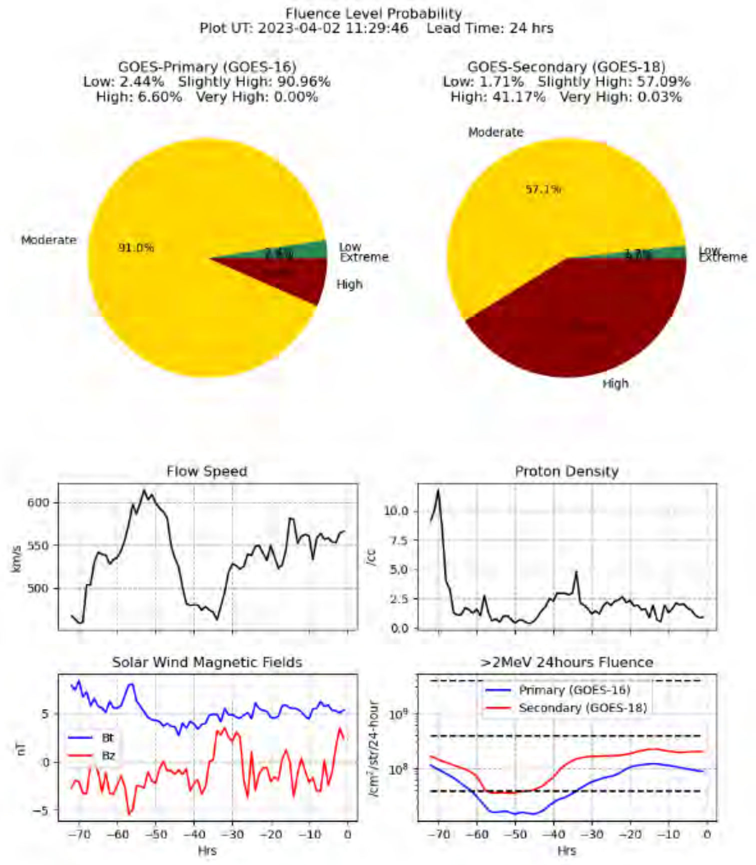


- Space Weather follow-on mission Lagrange 1 (SWFO-L1) is a deep-space mission planned by NOAA in USA, operating at Lagrange 1 (L1) point to monitor solar wind disturbances before they reach the Earth.
- A 7.3m diameter parabolic antenna was constructed at Kashima Space Technology Center, NICT in March 2023 for real-time receiving of SWFO-L1 observation data as a member of SWFO Antenna Network.

Applications for users related with high energy particles

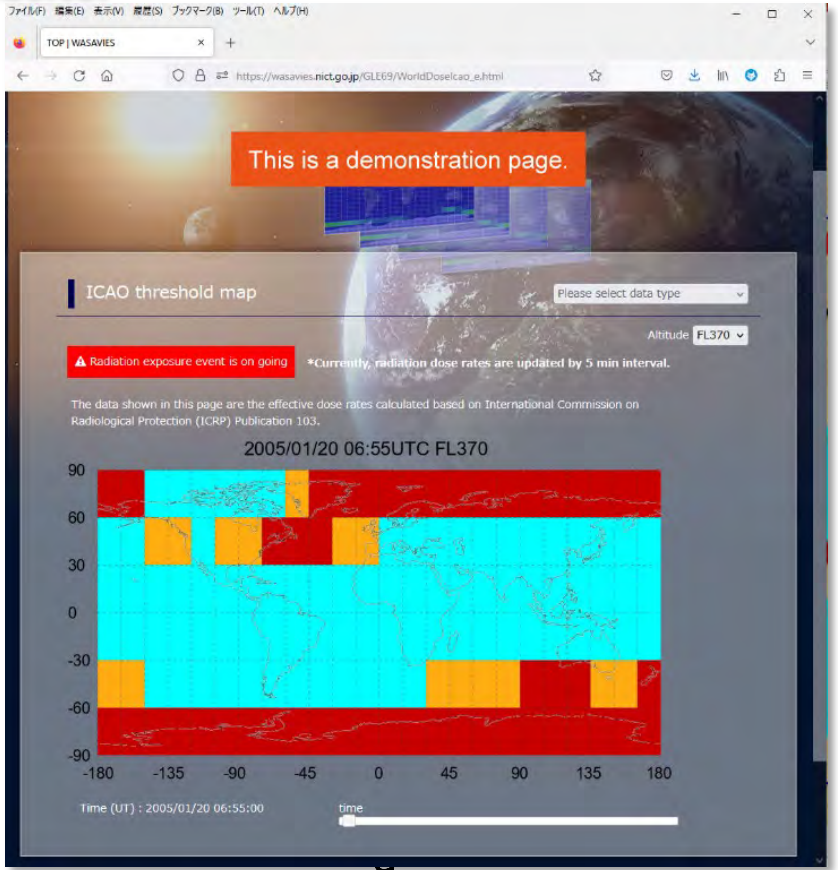
AI-based radiation belt electron forecast model (Rade-AI)

Develop AI-based radiation belt electron fluence probabilistic forecast model.



Improve WASAVIES

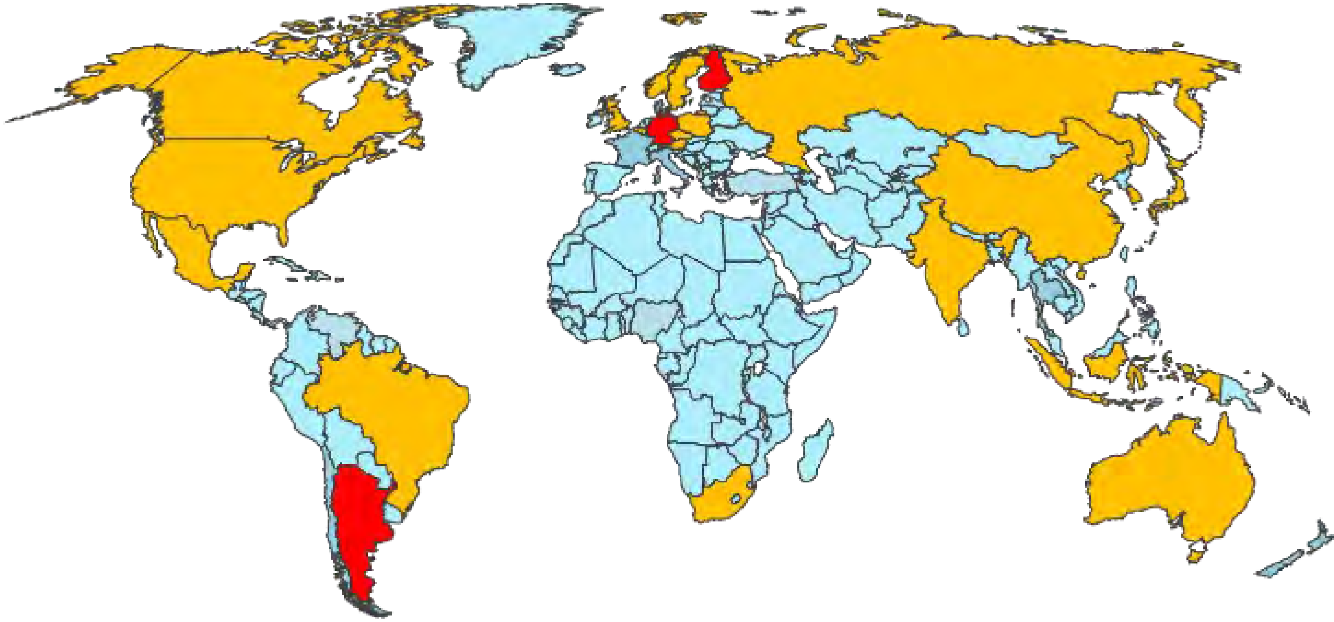
Release ICAO threshold map for radiation dose rate on WASAVIES (WArning System for AVIation Exposure to Solar energetic particle） website.



International Activities: ISES

International Space Environment Services (ISES)

- ISES is a community of organizations that provide operational space weather forecasting services and has been active since 1962.
- It is the only organization in the world that is active in space weather information distribution, and many of its members serve as core members of other space weather-related organizations.
- As of June 2024, 22 Regional Warning Centers, 4 Associate Warning Centers, and 1 Collaborative Expert Centers are members. Dr. Ishii of NICT, Japan was elected as Director in 2023.



ISES Member Countries
Yellow: Existing members
Red: Joining after 2020

International Activities: WMO-ISES-COSPAR

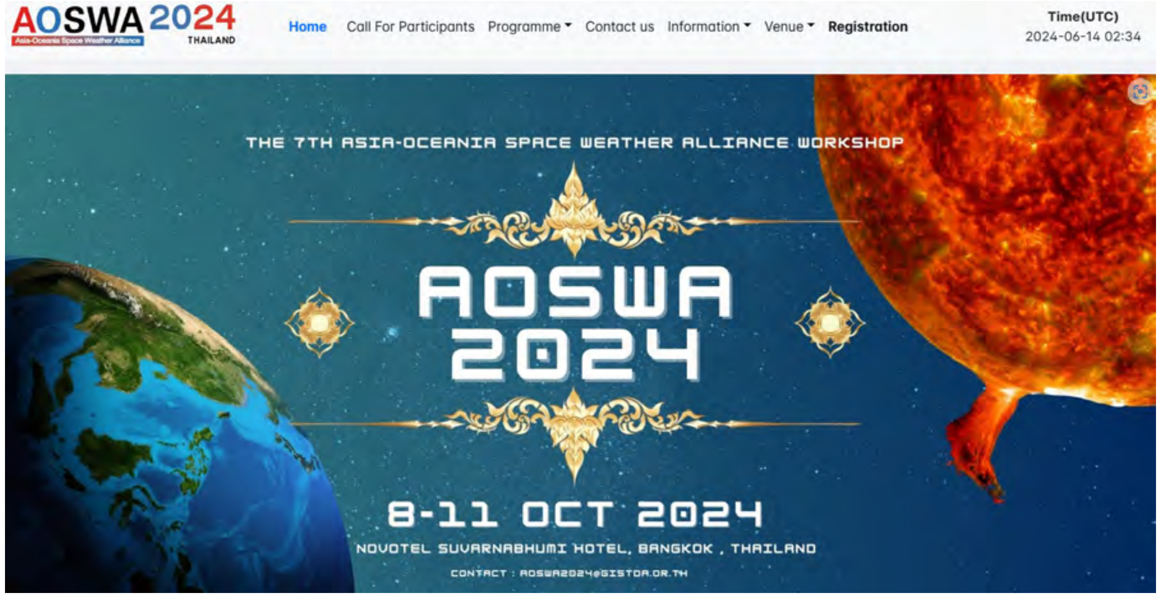
<u>WMO-ISES-COSPAR Collaboration</u>

- UN/COPUOS STSC issued recommendations on space weather services in February 2022. COSPAR-ISES-WMO is required to lead space weather related activities and has begun to consider.
- In September 2022, the three organizations discussed and prepared the "Coimbra Declaration". NICT contributed to this effort, as a representative of ISES.
- NICT also contributes to hold the first International Space Weather Coordination Forum (ISWCF) on November 2023 at WMO Headquarters in Geneva, Switzerland.

ISWCF meeting participants at WMO Headquarters, Geneva, November 17, 2023.

International Activities: AOSWA

- The Asia-Oceania Space Weather Alliance (AOSWA) established on 2010 for information exchange among Space Weather organizations in Asia and Oceania.
- Members: 27 organizations from 13 countries
- AOSWA workshop is held every one and a half years. The last meeting of AOSWA was held in October 2023 in Malaysia hosted by UKM.
- Next meeting is scheduled in Bangkok, Thailand hosted by GISTDA in Oct. 8-11, 2024.



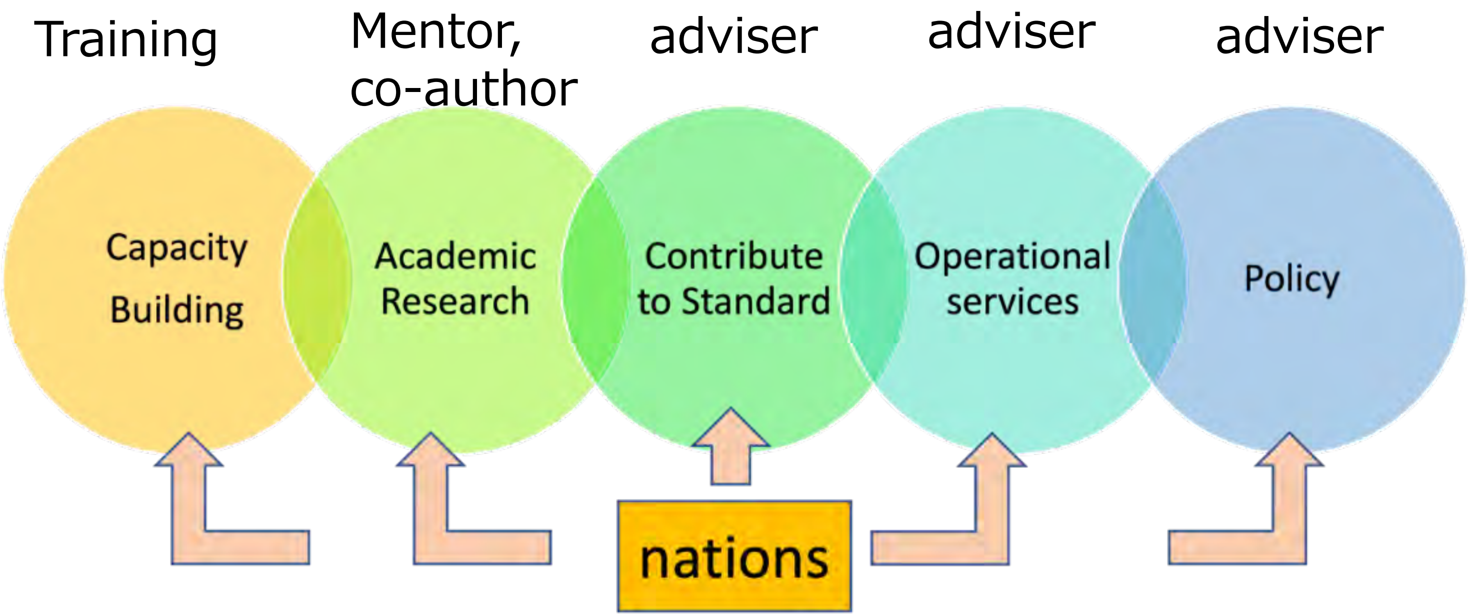
Abstract submission deadline: 30 June 2024

AOSWA-6 @ BANGI, MALAYSIA in 9 - 11 October 2023 hosted by UKM.

Fostering Asia-Oceania Countries in Developing Space Weather's Research Capacities Through AOSWA

Asia-Oceania Space Weather Alliance (AOSWA) 2023 special session: <u>Connect the Local Observation to Global Network</u>
Convener: Dr. Septi Perwitasari (NICT, Japan)
Co-convener: Dr. Shanzana Nurul (UKM, Malaysia)

Survey correct information on the local space weather research and observation (R&O) activities of AOSWA members



- Strategy to help developing countries tailored with their needs

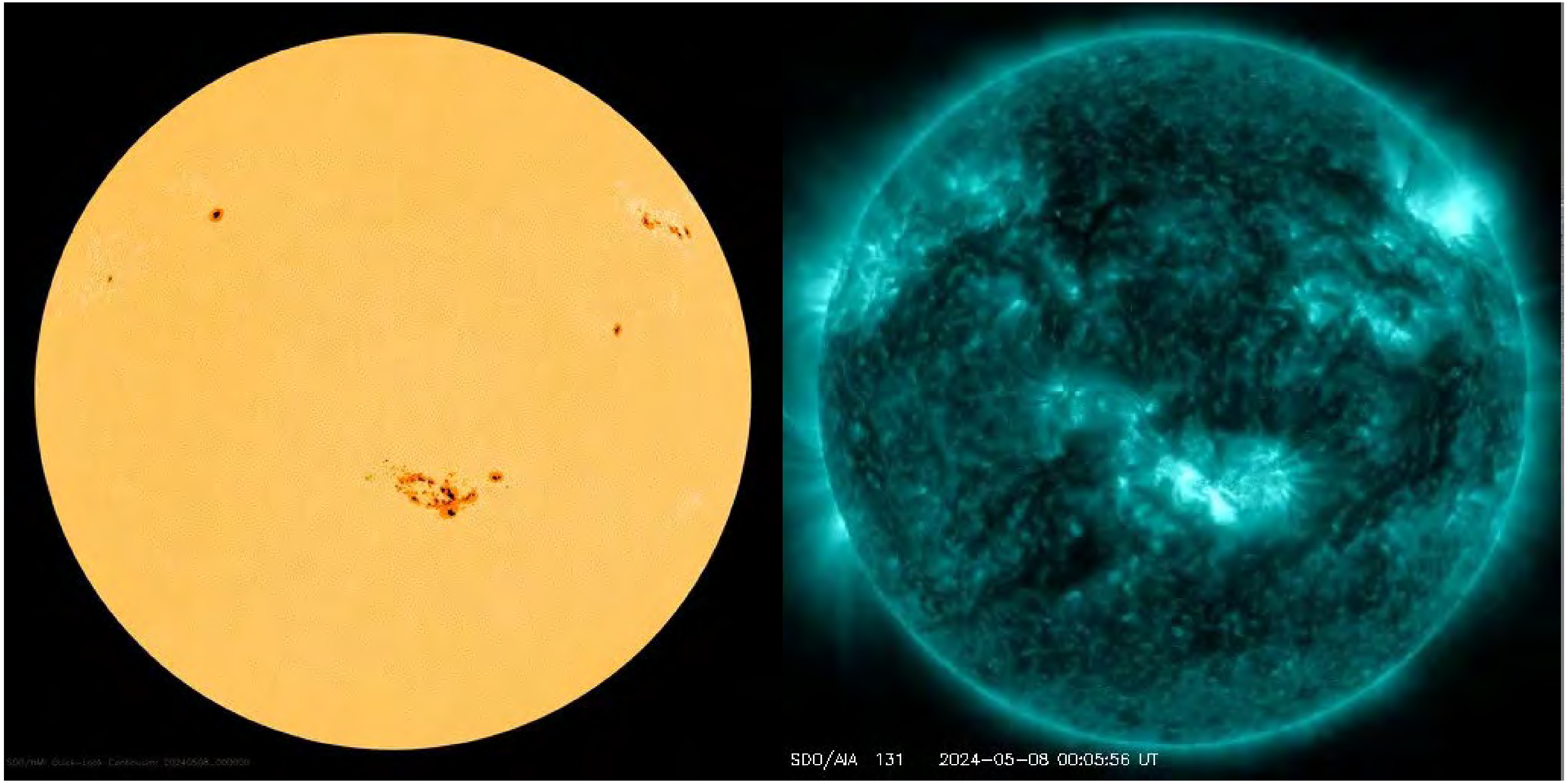
AOSWA 2024 session: <u>Connecting the Local Observation to Global Network and space weather services</u>
Convener: Dr. Septi Perwitasari (NICT, Japan)
Co-convener: Dr. Shanzana Nurul (UKM, Malaysia)

Activities for Capacity building in NICT

- NICT has an internship program to support the travel fare to NICT and staying expense for students.
- In addition, we have received staffs for giving training as space weather forecasters since 2014, especially from the South East Asian countries.

Period	Country	Affiliation	# of visitors
Jan. 2013	Korea	Kiyong Hee Univ.	2
Sep. 2014	Indonesia	LAPAN	2
Apr. 2014- Mar. 2015	Malaysia	UKM	1
Sep. 2015	Malaysia	ANKGASA	2
Sep. 2018	Thailand	KMITL	3
Oct.- Dec. 2022	Thailand	GISTDA	2

A brief report of 2024 May event



Solar images observed by SDO satellite (NASA, USA)
(left: visible light, right: ultraviolet light)

2024 May event: Alerts from NICT

Date	Space Weather Bulletins	Forecast (Daily Report)	Press release	Social impacts
8 May 2024	08 JST: X-class flare 11 JST: X-class flare 18 JST: full halo CME	• X-class flare probability ≧50% for the next 24h. • Geomagnetic storm will occur after 10th May		
9 May 2024	07 JST: X-class flare 09 JST: full halo CME 18 JST: X-class flare 20 JST: X-class flare 21 JST: full halo CME	• 15JST : X-class flare probability ≧50% for the next 24h. • Geomagnetic storm K≧7 will occur after 10th May		
10 May 2024	03 JST: X-class flare 16 JST: X-class flare 18 JST: full halo CME 23 JST: SEP	• 15JST : X-class flare probability ≧50% for the next 24h. • Geomagnetic storm K≧7 will occur for the next 24h	**16 JST: Space weather warning issued** **19 JST: Press conference (online)**	
11 May 2024	08 JST: Geomagnetic storm with K=8 (start at 02 JST 10 May). 11 JST: X-class flare 16 JST: full halo CME 21 JST: X-class flare	• Geomagnetic storm K≧7 will occur for the next 24h	**Media Response** (as of May 24, 2024) **Interviews: 61** Media coverage: Newspaper 114, TV 48, Web 588	• **Aurora** • **GPS error** • **HF communication error**

“multiple CME will soon arrive, and Space system may be affected”

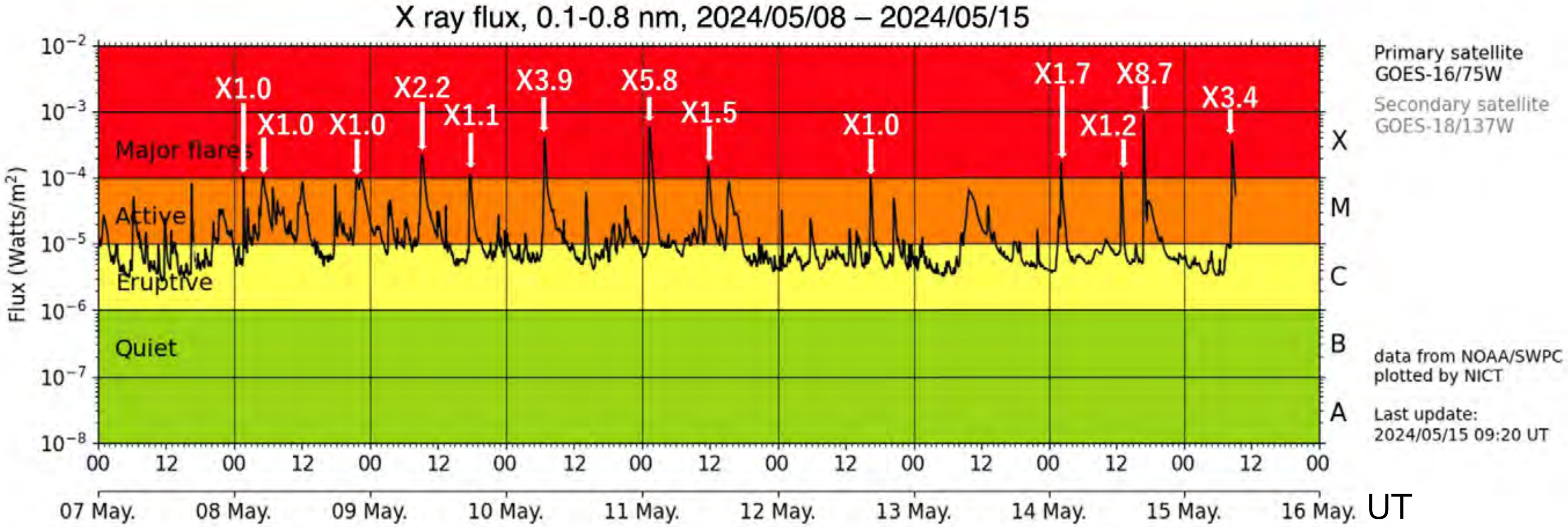
5月10日から数日間，宇宙天気変動に注意

X-class flares occurring between May 8 and 15, 2024

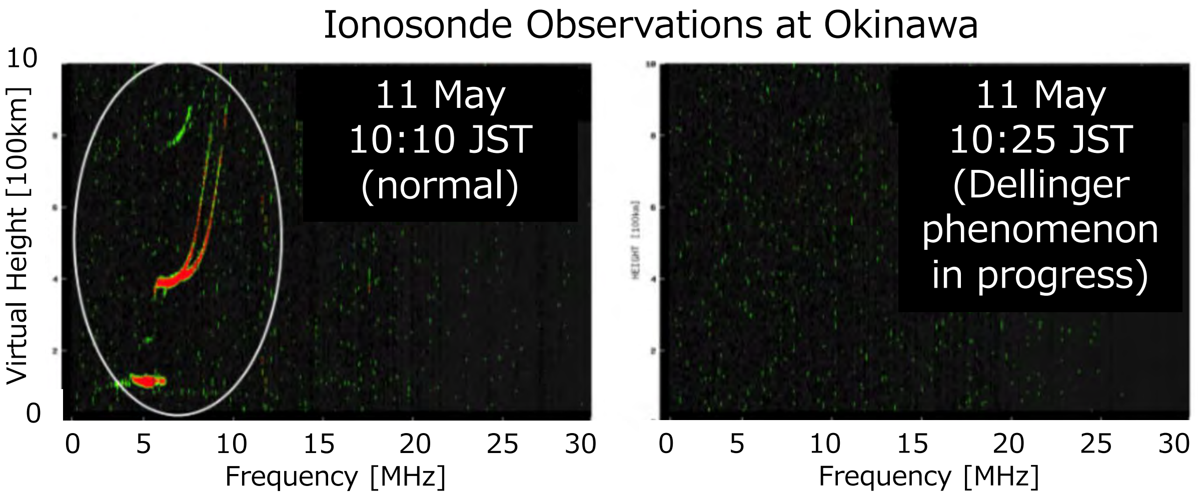
- **This is the first time in the history of GOES satellite observations (since 1975) that seven flares of X-class or greater have occurred in 72 hours.**
- **The largest flare was X8.7 on May 15, the largest in the current solar cycle 25.**

(Figure below) X-ray flux observed by the GOES satellite. The arrows in the figure indicate the occurrence of X-class solar flares.

No.	Date	Time（JST）	Class
1	8 May 2024	10:41	X1.0
2	8 May 2024	14:09	X1.0
3	9 May 2024	06:40	X1.0
4	9 May 2024	18:13	X2.2
5	10 May 2024	02:44	X1.1
6	10 May 2024	15:54	X3.9
7	11 May 2024	10:23	X5.8
8	11 May 2024	20:44	X1.5
9	13 May 2024	01:26	X1.0
10	14 May 2024	11:09	X1.7
11	14 May 2024	21:55	X1.2
12	15 May 2024	01:51	X8.7
13	15 May 2024	17:37	X3.4



Short-wave fadeout (Dellinger phenomenon)



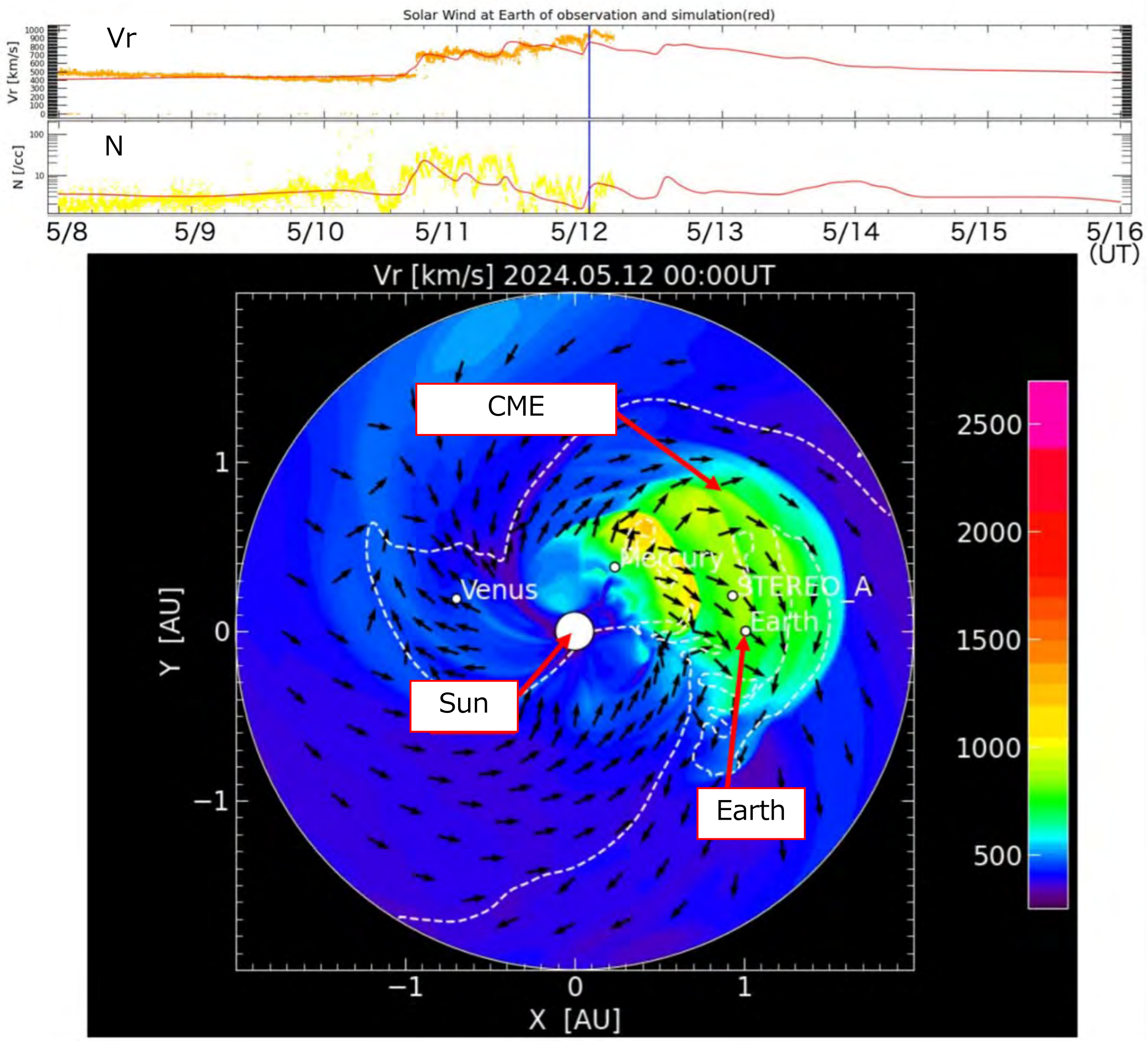
Date	Time（JST)	Observatory (Level)
8 May 2024	10:45	W, K, Y, O
8 May 2024	11:30	W, K, Y, O
8 May 2024	13:30 – 14:30	W, K, Y, O
9 May 2024	06:30 – 08:15	W, K, Y, O
9 May 2024	12:15 – 12:45	W, K, Y, O, (Weak)
9 May 2024	15:15	K, Y, O, (Weak)
10 May 2024	12:30	K (Weak)
10 May 2024	15:45分 – 16:15	W, K, Y, O
11 May 2024	10:15分 – 11:45	W, K, Y, O
12 May 2024	09:45	W, K, Y, O
14 May 2024	11:15	W, K, Y, O
15 May 2024	17:45	W, K, Y, O（Weak)

- List of Dellinger phenomena observed by NICT's Ionosondes from May 8 to 15 (right table) and examples of observed images (upper figures).

- Ionospheric observation by Ionosonde (Ogimi, Okinawa). The normally observed ionospheric echoes in the white circles were absorbed in the lower part of the ionosphere and disappeared.

- It is highly likely that **shortwave band communications were disrupted during the time period** when the Dellinger phenomena occurred.

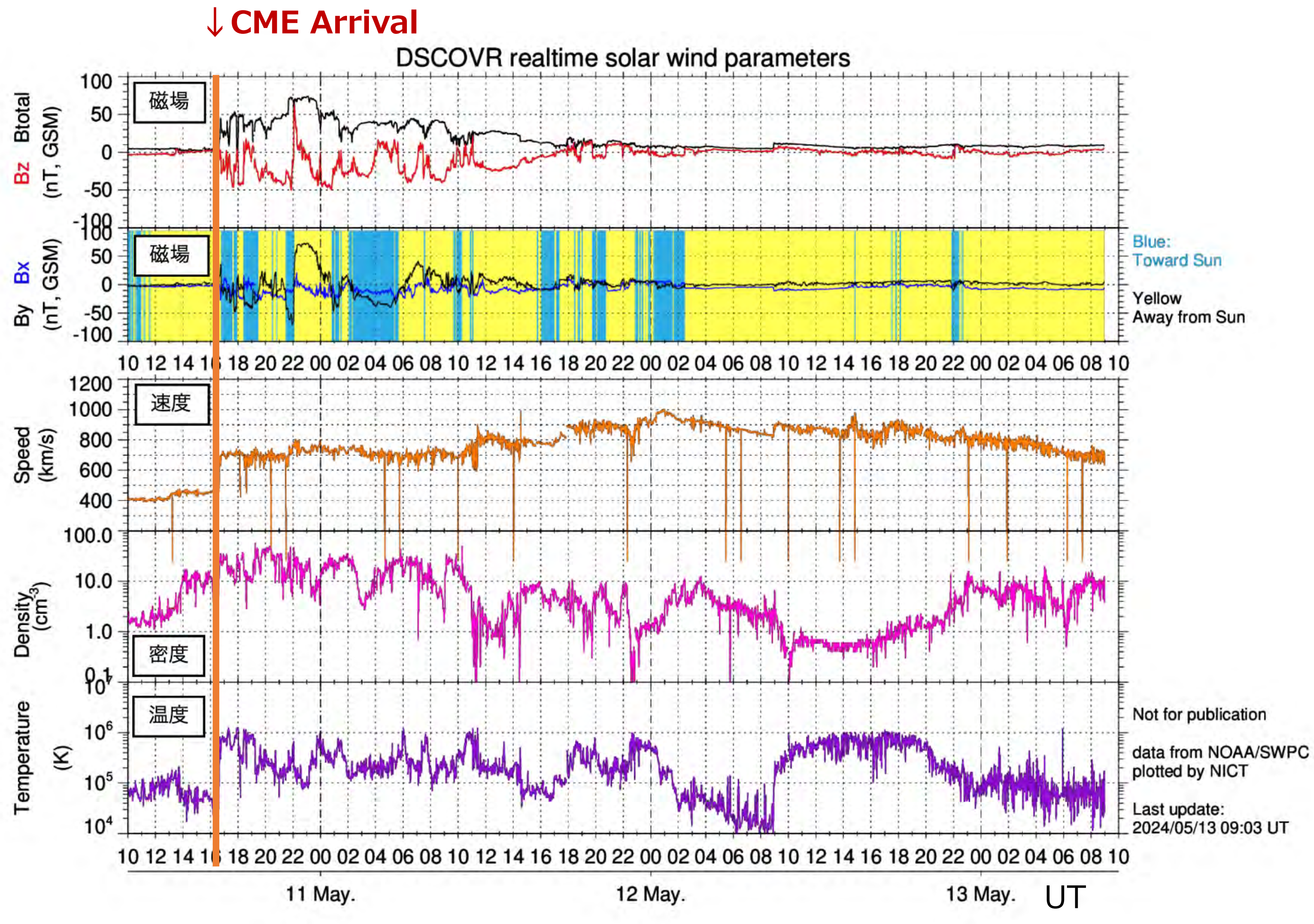
Solar wind simulation



- NICT's solar wind simulation "SUSANOO" predicts the arrival of CMEs.
- It visualizes that CMEs ejected multiple times in conjunction with solar flares and passed around the earth in clumps.
- **The first arrival of CME was predicted by SUSANOO from the night of 10 May to 11 May**.

(Upper panel) Predicted variations in solar wind speed and density arriving at the earth
(Lower figure) Distribution of solar wind velocity in interplanetary space at 9:00 AM on 12 May JST.

Solar wind



- **CME arrived around the earth at around 01:30 on 11 May (JST).**
- With the arrival of the CME, the velocity of the solar wind increased rapidly to 770 km/s and the magnetic field strength to 72 nT, and the north-south component of the magnetic field temporarily turned very strongly southward at around -50 nT.
- After 8 May, multiple CMEs passed around the earth one after another.

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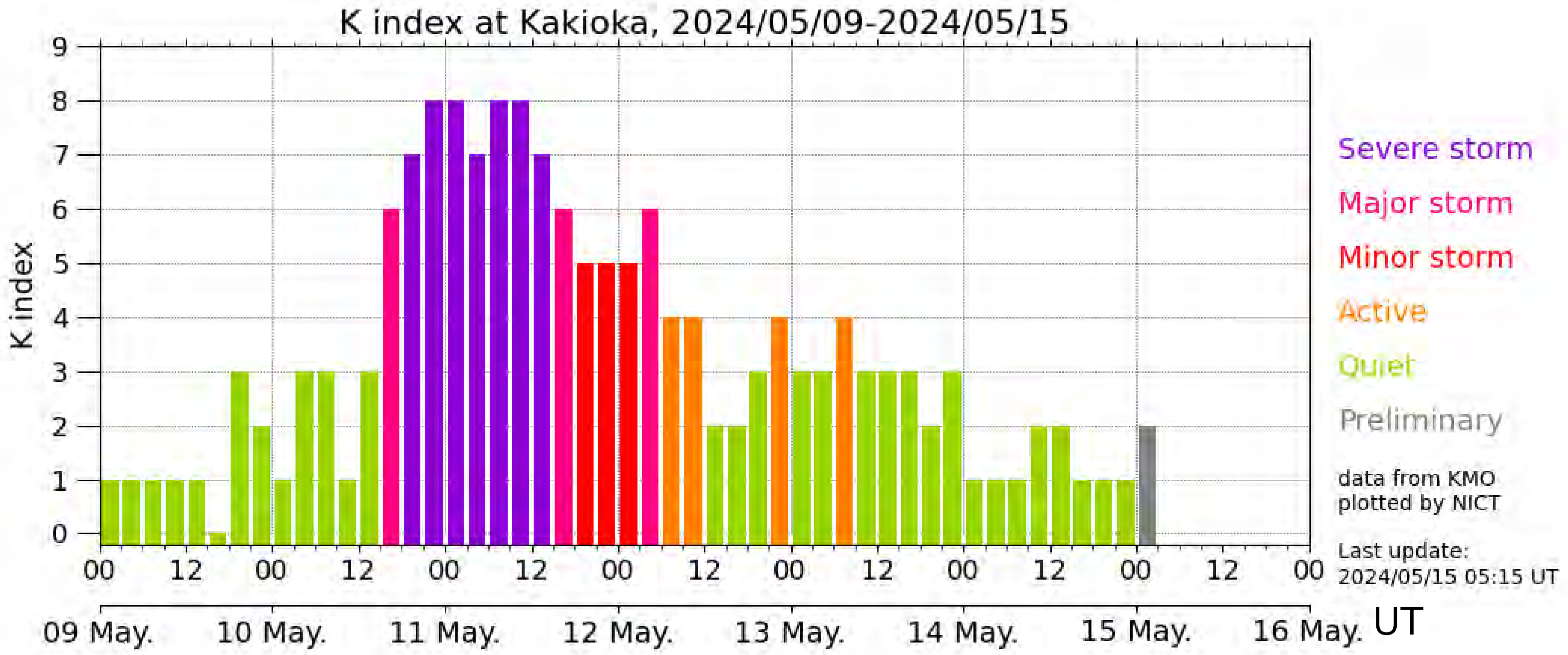
Geomagnetic field variation

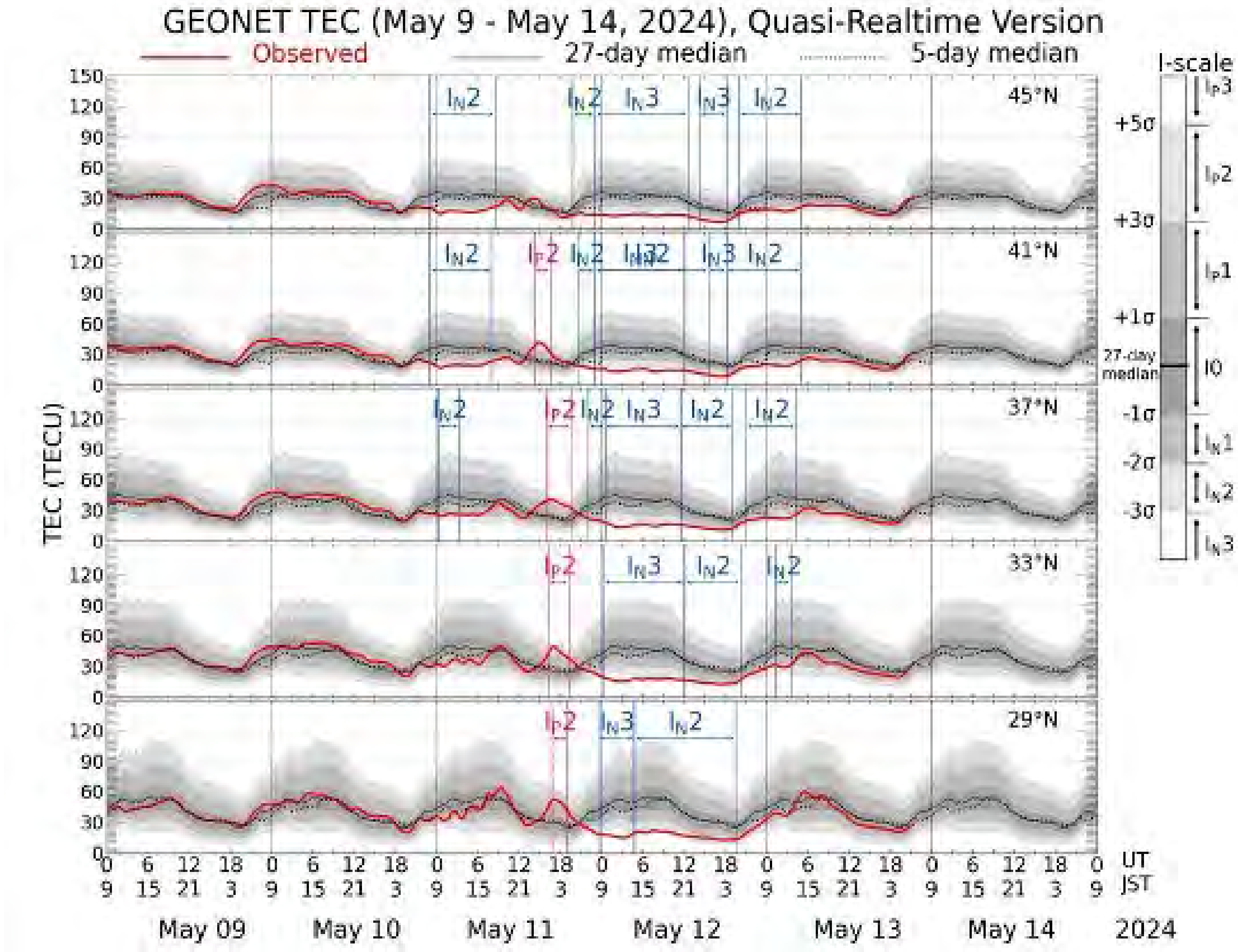


Tentative geomagnetic index values from the JMA Geomagnetic Observatory (Kakioka).

- According to the JMA Geomagnetic Observatory (Kakioka, Japan), a rapid onset **geomagnetic storm occurred at 02:05 JST on May 11**.
- The maximum change in the horizontal component of the geomagnetic field associated with this geomagnetic storm was about 532 nT.

- During this period, the **K index, which indicates geomagnetic disturbance, was "8"** four times, the second from the top out of ten levels.
- The last time a K index of "8" was observed at the geomagnetic observatory (Kakioka) was in August 2005, making this **the first large-scale magnetic storm in about 19 years**. This geomagnetic storm ended around 13:00 on the 14th.

Ionospheric variation



Total electron content over Japan calculated from GSI GEONET data

- In association with the occurrence of geomagnetic storms, **large-scale ionospheric negative-phase storms were confirmed** over Japan.
- In addition, the occurrence of an **ionospheric positive-phase storm was confirmed** south of northeastern Japan during the nighttime on May 11.

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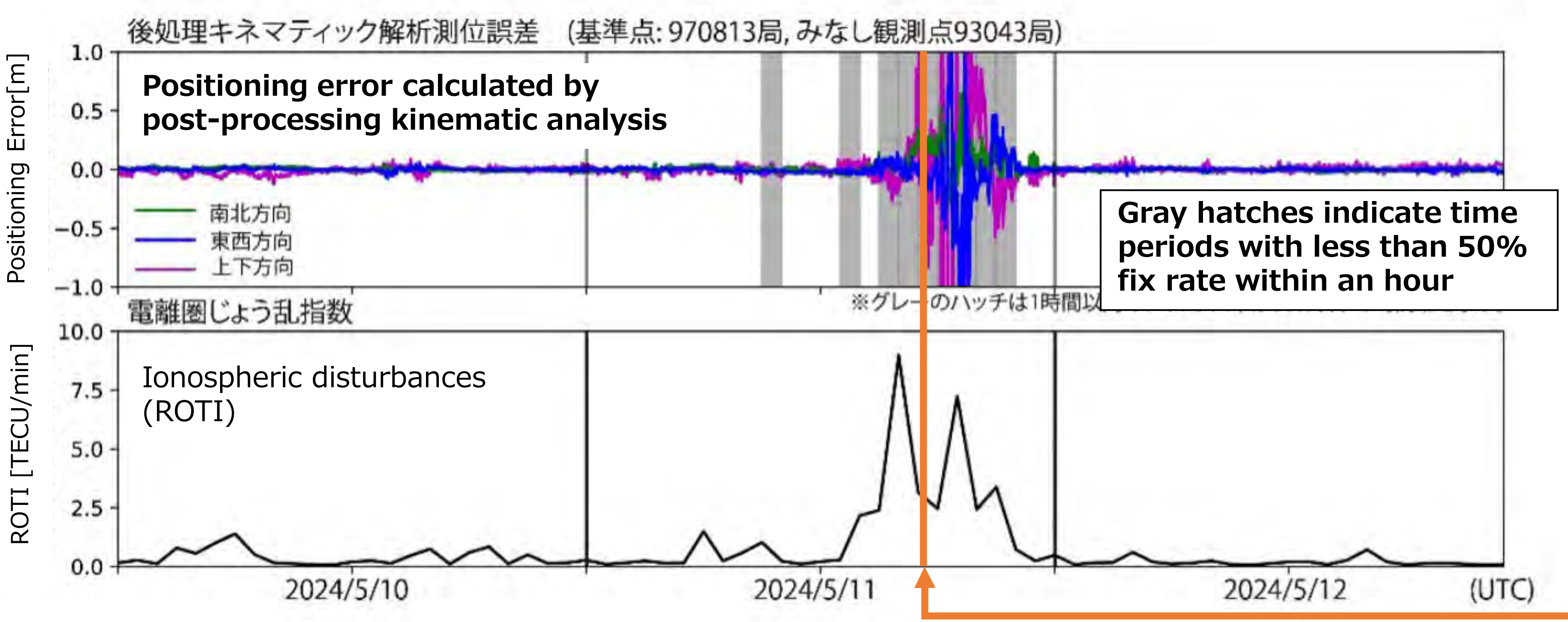
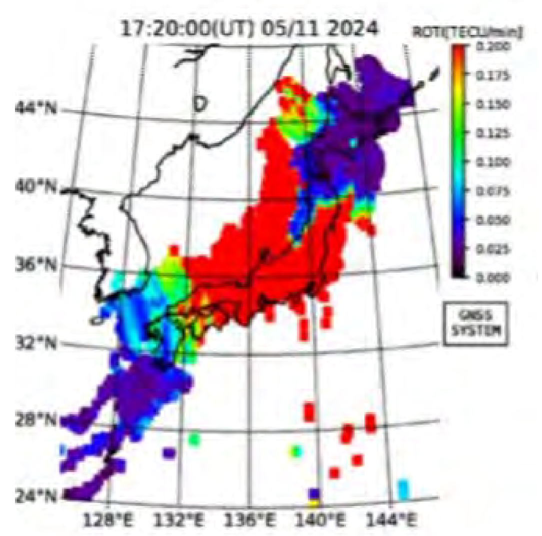
Ionospheric disturbances and GNSS positioning error



5/12 02:20 JST ROTI map



- According to the Ionospheric Disturbance Index (ROTI) map, **ionospheric disturbances passed over Japan** from after 21:00 JST on 11 May to dawn on 12 May **during the period when a positive-phase ionospheric storm was observed**.
- During the time period when the increase in ROTI was observed, **the positioning error calculated by post-processing kinematic analysis was confirmed to have increased**.
- Relative positioning such as RTK-GNSS, which uses position information from reference stations, may have been affected.

Social impact (1/2)

Field	Location	Impact	Major Impacts
Satellite Operation	Japan	✓	• Sony's satellite “EYE” **dropped 400 meters in altitude. A reset of the attitude control system functions** occurred. There was a **communication path operation that never downlinked**. https://www.itmedia.co.jp/news/articles/2405/22/news103.html
	USA		• Starlink satellites were reportedly unaffected. https://x.com/SpaceX/status/1789838269418471902
GNSS(GPS,QZSS, etc)	Japan	✓	• According to Geospatial Information Authority of Japan (GSI), the **single-frequency single-point positioning used for car navigation systems, etc., had a time zone of large error** from around 9:00 on 11 May to 6:00 on 12 May. In addition, the **GNSS positioning system used for surveying may have been affected** by ionospheric disturbance at certain times between midnight on 11 May and early morning on 12 May. https://www.gsi.go.jp/denshi/denshi45043.html (1st report) https://www.gsi.go.jp/denshi/denshi45044.html (2nd report) • During the period when ionospheric disturbance was observed, **there was a disturbance of sea level values on several GPS wave gauges**. NOWPHAS https://nowphas.mlit.go.jp/sp/pg_choui/804/20240511 https://nowphas.mlit.go.jp/sp/pg_choui/804/20240512 • Several GNSS positioning service providers and users reported that single-frequency relative positioning, RTK positioning, etc. were affected. (NICT survey)
	USA	✓	• **Some GPS systems were temporarily offline and the accuracy of the RTK system was also skewed**, affecting the planting of crops with GPS farm equipment. https://www.theverge.com/2024/5/12/24154779/solar-storms-farmer-gps-john-deer

Social impact (2/2)

Field	Location	Impact	Major Impacts
Communications, Broadcasting, Radar	Japan	✓	• There were reports that **HF communications used in amateur radio were affected**. https://www.hamlife.jp/2024/05/11/magnetic-storm/
	USA	✓	• NOAA reported that power, HF communications, and GPS were impacted. https://www.swpc.noaa.gov/news/g5-conditions-reached-yet-again
	S. Africa	✓	• **HF communication disrupted** in South Africa. https://www.sansa.org.za/2024/05/the-mothers-day-solar-storm/
Aviation	Domestic/international		• **Several domestic and international aviation-related operators implemented alerts and warnings based on actual space weather conditions and forecast information**. Some took action such as **changing air routes**. There were reports of **temporary disruptions in shortwave communications**, but there were no reports of flight suspensions or other effects. (NICT survey)
Electric Power	Japan, Canada		• No specific impacts have been reported.
	New Zealand		• **Some transmission services were shut down in advance.** No impact was found. https://www.1news.co.nz/2024/05/12/solar-storm-transpower-extends-grid-emergency-declaration/
Sightseeing	Domestic/international		• There were **numerous reports of auroras** being observed around the world, including in Japan and other mid-latitudes.

The first national document for space weather in Japan

NICT

In Japan, “Study Group on the advancement of space weather forecasting” was established in the Ministry of Internal Affairs and Communications (MIC). The report of the study group (in Japanese) was published in June 2022.

宇宙天気予報の高度化の在り方に関する検討会

報　告　書

「文明進化型の災害」に対応した

安全・安心な社会経済の実現に向けて

令和 4 年（2022 年）6 月 21 日

Worst-case scenario for extreme space weather events occurring once per 100 years or less (excerpts)

- Communications and broadcasting are intermittently disrupted, causing socioeconomic disruption. Cell phone service is also suspended in some areas.
- Satellite positioning accuracy deviates by up to several tens of meters. Collision accidents with drones and other vehicles occur.
- Many satellites are damaged. A significant number of satellites are lost. Satellite-based services are suspended.
- Aircraft and ship operations are suspended worldwide. Significant disruptions to schedules and plans.
- Widespread power outages in non-resilient power infrastructure

New alert criteria considering social impact

Negligible impact　Possibility of minor impact　Possibility of impact　Possibility of severe impact

* Criterion can change due to future research　■ Criterion that depends on the system　△ Criterion that are "unusual" rather than failures
(The physical quantity described in each Lv is the threshold)

Impact and damage	Space weather phenomena / physical quantities that can cause damage	Social impacts and criteria				
		(Area / Orbit)	Lv 1	Lv 2	Lv 3	Lv 4
	Geomagnetic storm substorm Substorm particles		**Criterion:** K=4 or less	**Criterion:** K=5	**Criterion:** K=6	**Criterion:** K=7 or more
Deep charging **Malfunction or failure of satellite**		LEO				■
		MEO			*	*
		GEO			■	■
		(Non-Earth orbit)	-	-	-	-
Surface charging **Malfunction or failure of satellite**		LEO		■	■	■
		MEO		*	*	*
		GEO		■	■	■
		(Non-Earth orbit)	-	-	-	-
Increase in air drag **Satellite attitude and orbit change**		LEO	(altitude dependent) *	(altitude dependent)	(altitude dependent)	(altitude dependent)
		MEO	-	-	-	-
		GEO	-	-	-	-
		(Non-Earth orbit)	-	-	-	-
	Radiation belt electrons increase High energy electrons (> 2 MeV)		**Criterion:** Less than 3.8 x 10^7cm-2 sr-1	**Criterion:** 3.8 x 10 ^7 cm-2 sr-1 or more Less than 3.8 x 10^8 cm-2 sr-1	**Criterion:** 3.8 x 10^8 cm-2 sr-1 or more Less than 3.8 x 10^9 cm-2 sr-1.	**Criterion:** 3.8 x 10^9 cm-2 sr-1 or more
Total dose increase Degradation of satellite semiconductors and materials		LEO				*
		MEO				*
		GEO				*
		Altitude：50,000 km or more	-	-	-	-
Deep Charging (ESD) Malfunction or failure of satellite		LEO			*	*
		MEO			*	*
		GEO			■	■
		Altitude：50,000 km or more	-	-	-	-
	Proton phenomenon High energy protons (> 10 MeV)		**Criterion:** 100 PFU or less	**Criterion:** 100-1,000PFU	**Criterion:** 1,000-10,000PFU	**Criterion:** 10,000 PFU or more
Single-event effect Malfunction or failure of satellite		LEO	△	■	■	■
		MEO		■	■	■
		GEO		■	■	■
		Non-Earth orbit		■	■	■
Rapid increase in total dose Degradation of satellite semiconductors and materials		LEO		■	■	■
		MEO		■	■	■
		GEO		■	■	■
		Non-Earth orbit		■	■	■

https://www.soumu.go.jp/main_sosiki/kenkyu/space_weather/index.html

Development of NICT warning operation system for new warning criteria

Target field

HF Communications and broadcasting, Space system operation, aviation human exposure

→ The criteria in these fields have been considered and determined in the Study Group.

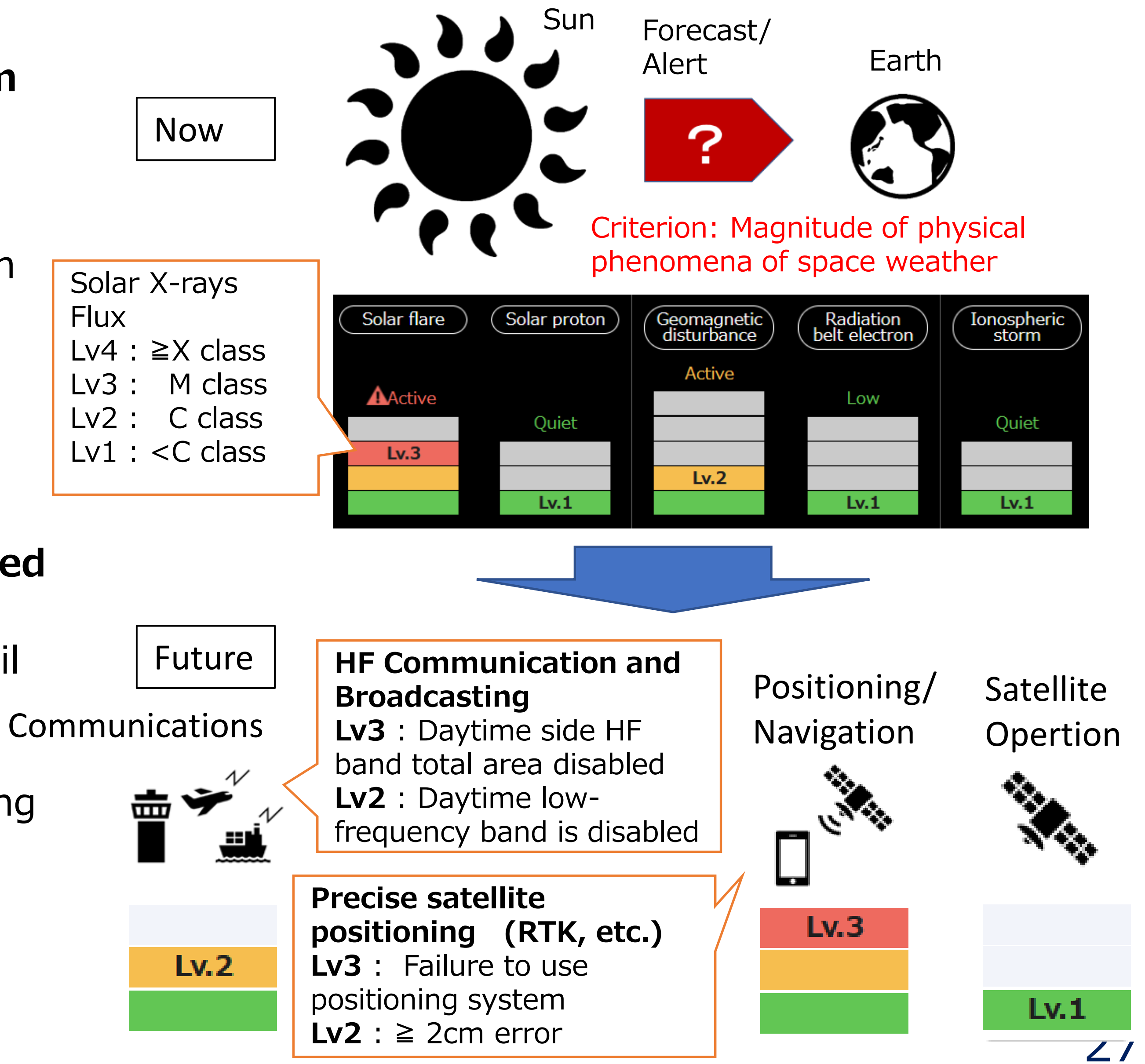
The other criteria will be added into operation system after determination.

Contents and timing of warnings

- **Three levels: Normal, Yellow (caution), Red (warning) in each field**
- **E-mail is automatically disseminated in case that the observation values exceeds the Yellow and Red criteria.**
- Social impacts in each field are described in the e-mail according to the levels.
- **In case of the red level of solar flare, NICT will manually disseminate an additional report** including detail forecasting.

Schedule and method

- The new warning system will be operated in parallel with the current warning system and is planned to open for public in 2024.



Summary

- In Japan, we are working on RMS project to develop instruments to measure energetic particles in GEO for safe and stable use of satellite operation, aviation and human activities in space. EM development is almost completed and we will proceed to FM development.
- We has been constructed a 7.3m diameter parabolic antenna at Kashima for real-time receiving of SWFO-L1 observation data as a member of SWFO Antenna Network.
- We contribute to international activities such as ISES, WMO, COSPAR, ITU, ICAO, etc. and to capacity building through giving training as space weather forecasters and communications through AOSWA.
- Since the space weather event in May 2024 is expected to have a significant social impact, a press conference was held to alert the public. Social impacts on GNSS, satellite operations, and communications were reported.
- We have developed a warning operation system for new criteria based on the report of “Study Group on the Advancement of Space Weather Forecasting” published in June 2022.