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Guidelines for Space Weather Research and Operation proposed by Space Weather Expert Group in UNCOPUOS

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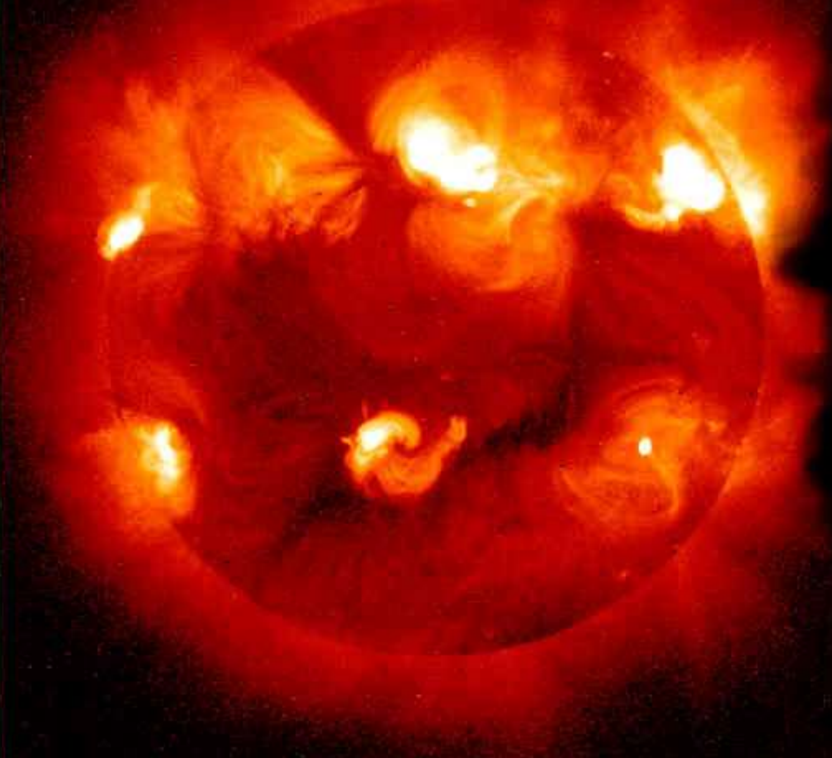
- Chair of COSPAR Space Weather Panel 2006-2008

- Vice-chair of COSPAR Space Weather Panel 2002-2006 and 2008-2016

- Co-chair of expert group on space weather (EG C) Long-term sustainability in outer space (LTS) WG UNCOPUOS, 2011-2015

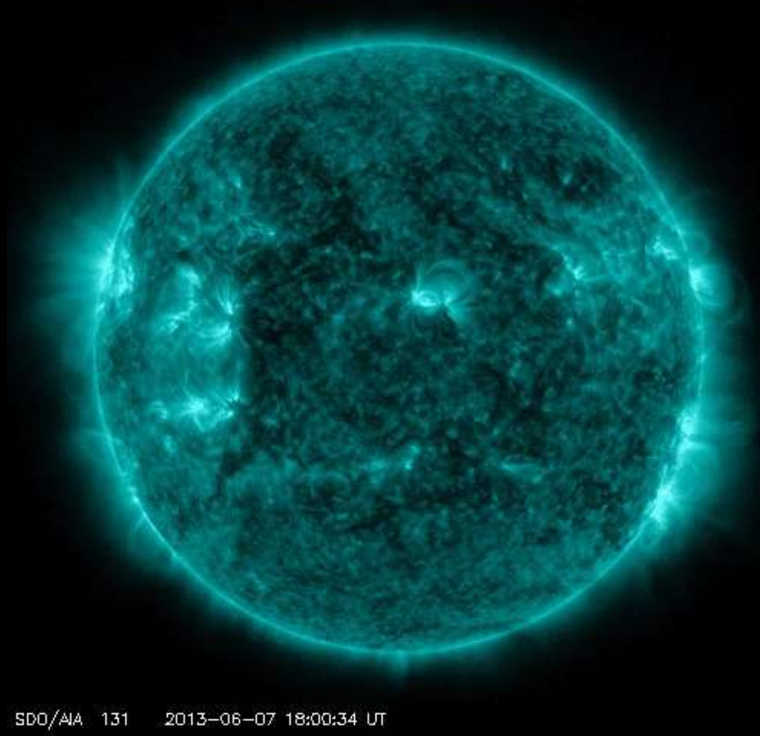
Outline of the presentation

1. Risks of Space Weather
2. Space Weather Guideline
3. Space Weather Forecast
4. Monitoring of Space Weather



Space Weather – Harmful Space Environment

Space is not empty.
Solar wind travels through space and the magnetosphere is formed in the vicinity of the Earth.



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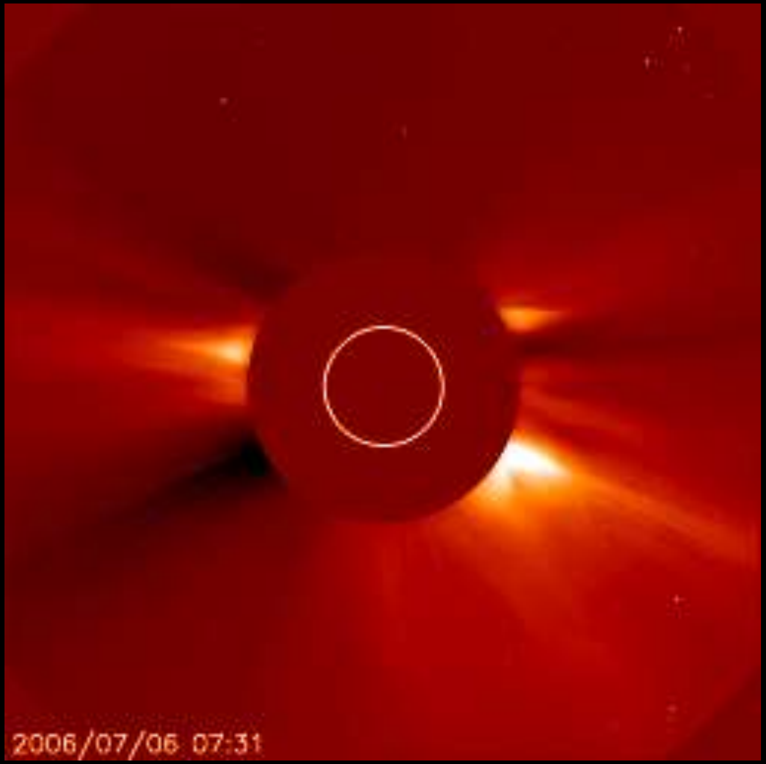
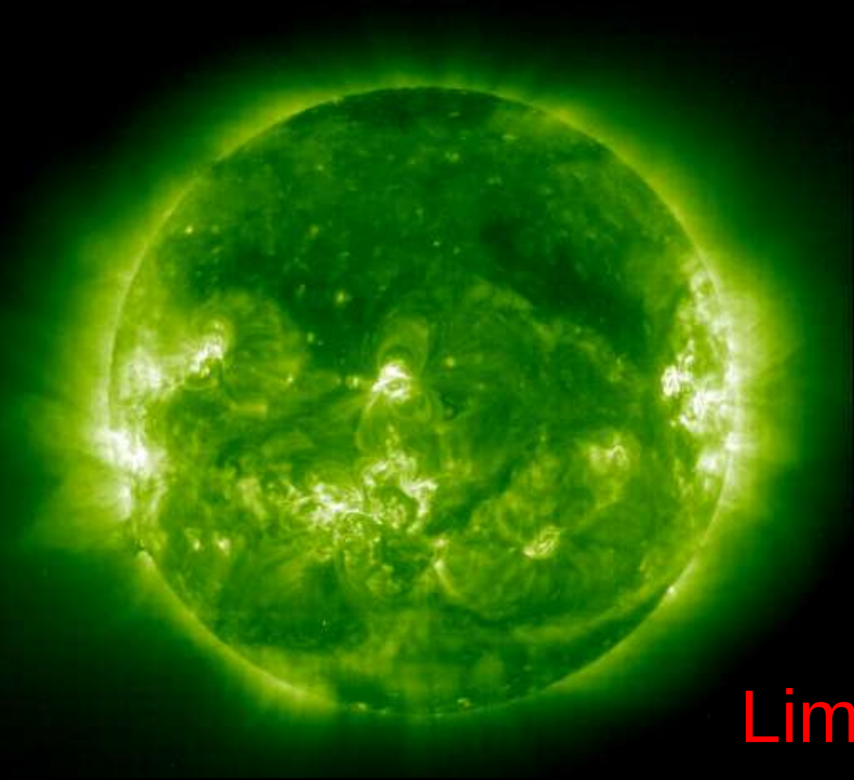
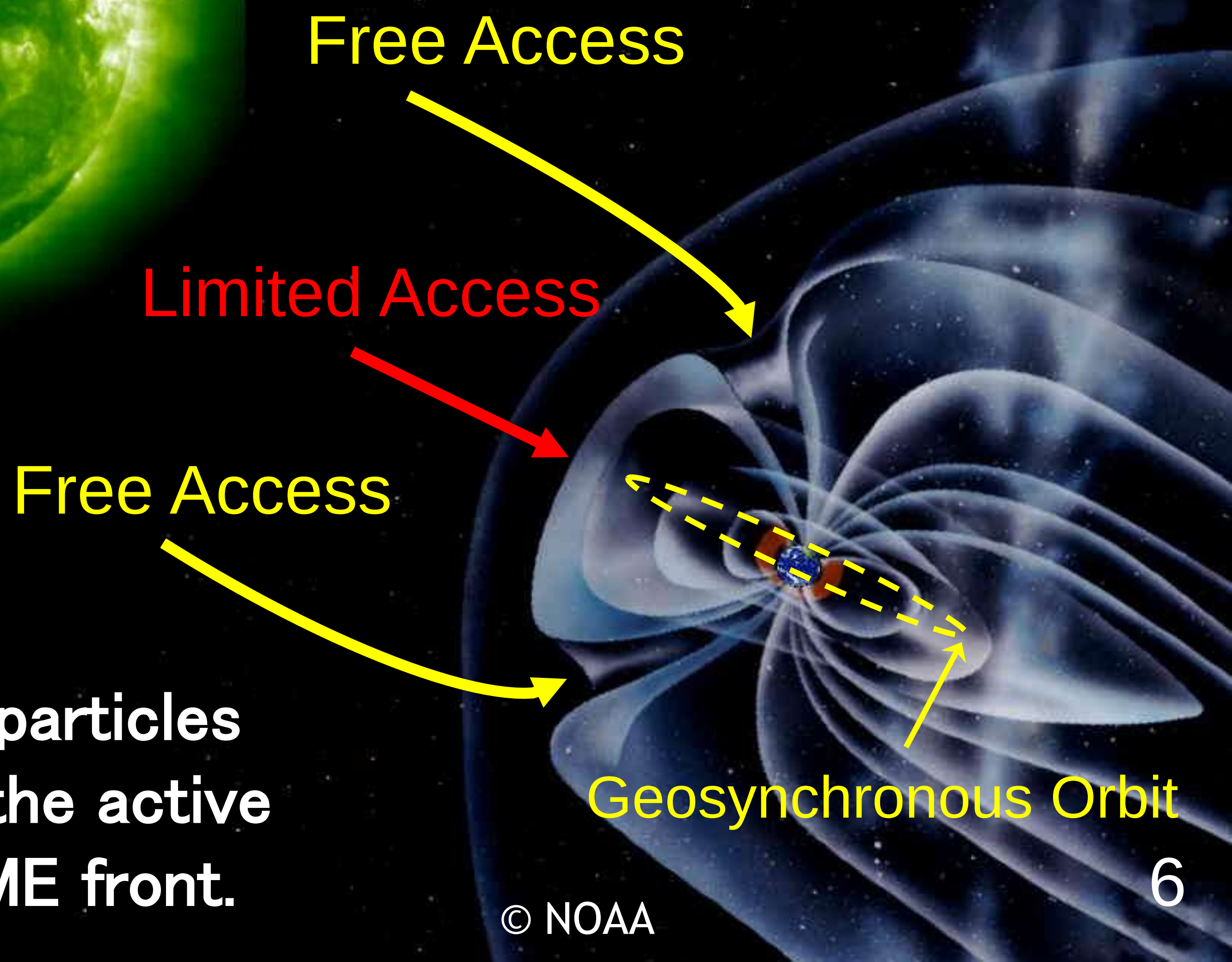


© NASA/ESA

When the solar flare occurs, a large amount of corona gases are emitted from the Sun. They are called CME (coronal mass ejection) and some of them reach the Earth, causing magnetic storms.

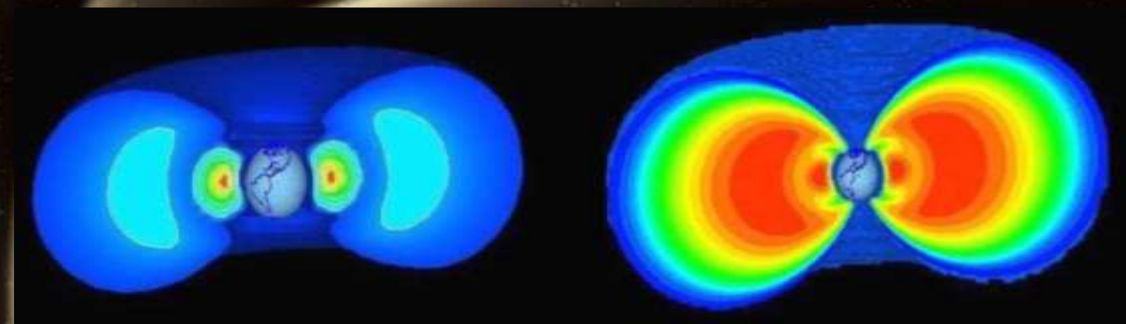
Solar Energetic Particle Access to Earth

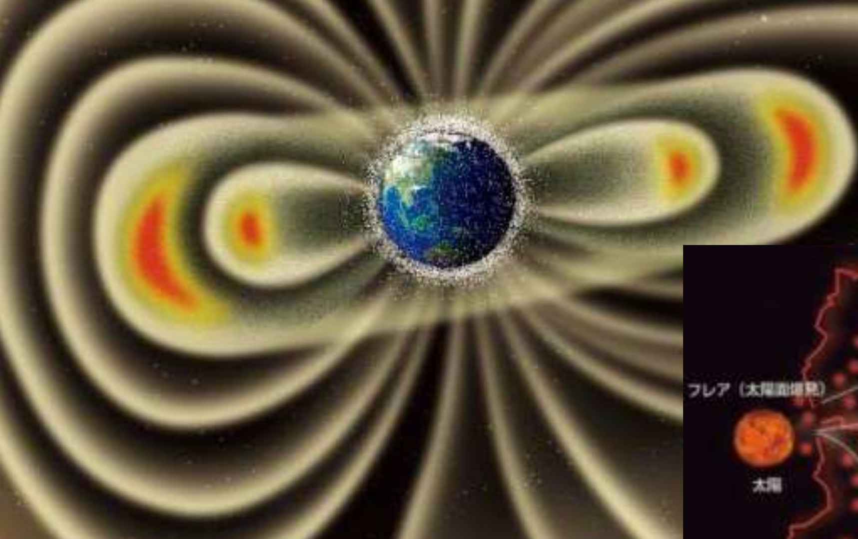




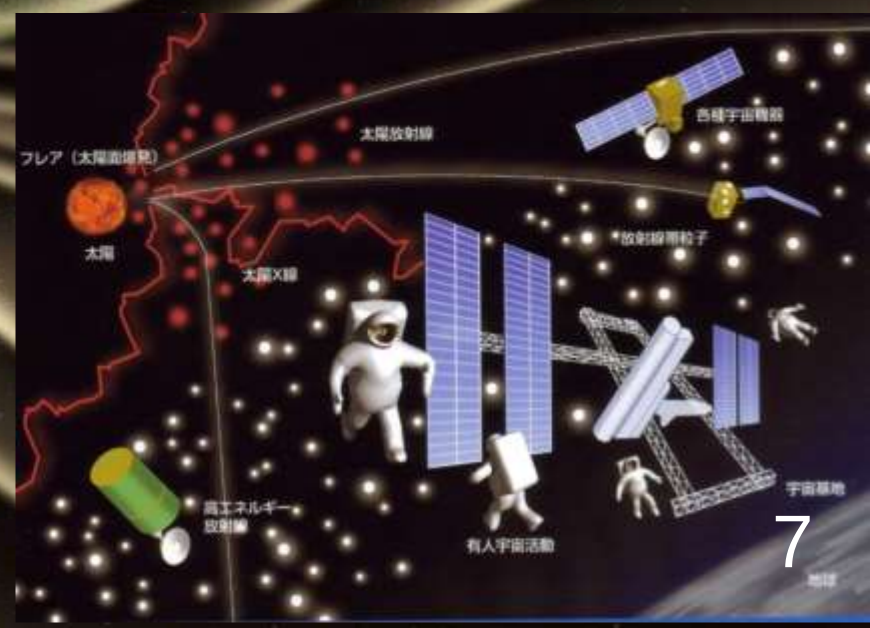
Highly energetic particles are produced in the active region and/or CME front.

When a magnetic storm occurs, radiation belts are filled with plenty of highly energetic electrons especially in the outer belt region





Storms create risks not only for satellites but also for astronauts.



Increasing Vulnerabilities to Space Weather

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- Satellite-based applications:
  - Navigation and communication
  - Environmental monitoring and research
  - Broadcast television and radio
  - Business and finance
- HF communication – wireless technology
- Electric power grid
- Airline safety
  - Navigation and communication
  - Radiation
- Marine applications

Space Weather Impacts on Space Sustainability

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1. Satellite Electronics
   - Single event upsets
     (energetic protons, heavy ions)
   - Deep dielectric charging
     (energetic electrons)
   - Surface charging
     (low energy electrons)
   - Surface corrosion
     (low energy oxygen)
2. Satellite Orientation
   - Star tracker anomalies
     (energetic protons)
   - Magnetic field variability
     (magnetopause crossings)

Space Weather Impacts on Space Sustainability

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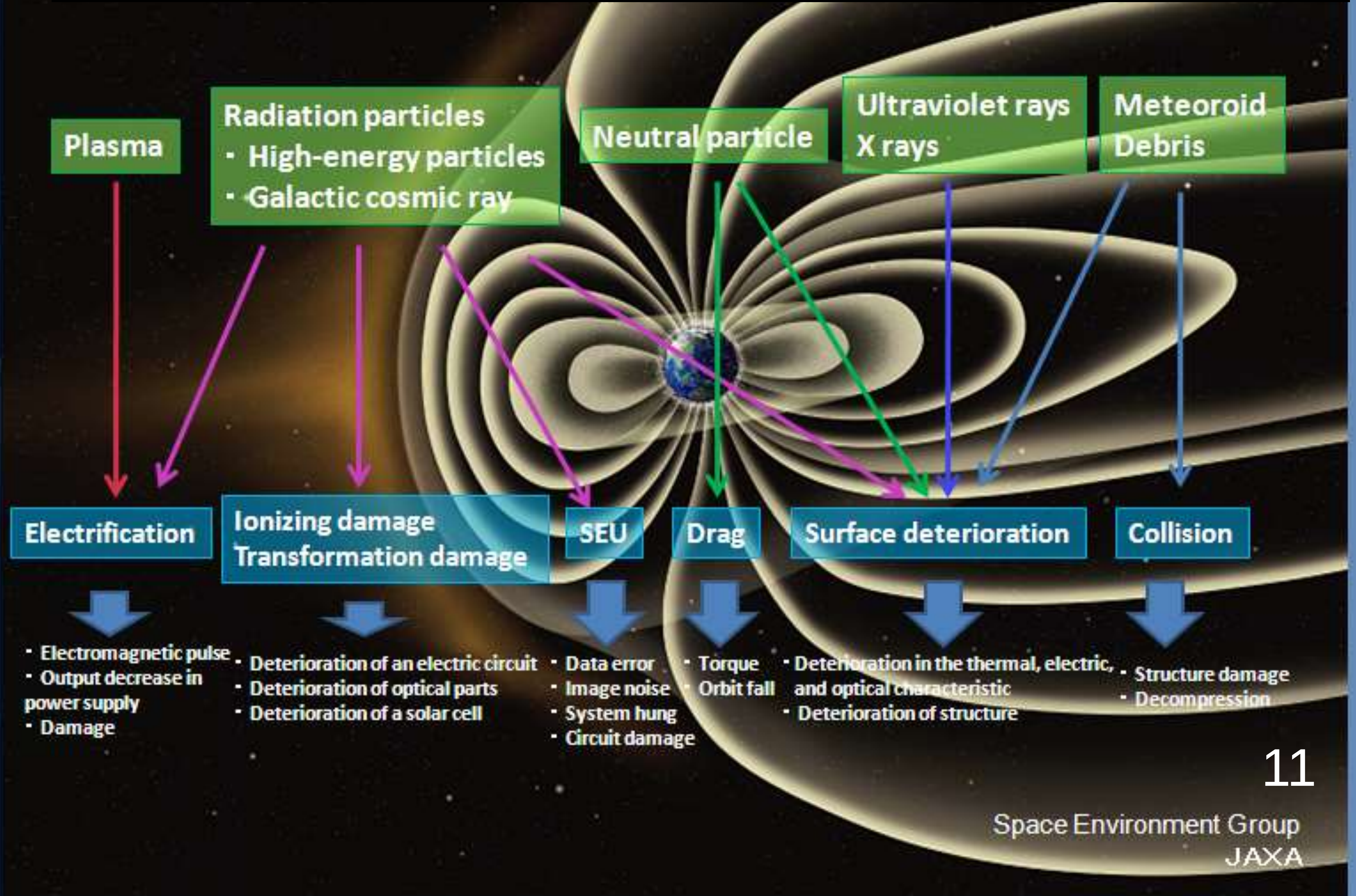
3. Satellite Communication
   - Ionospheric disturbances, solar radio interference
4. Satellite and Debris Orbit Determination
   - Neutral density variability
5. Human Health
   - Radiation impacts (energetic protons, ions, and electrons)

Space Environment Effects on Satellites



Space weather risks (1/3)

	Item	Influence and concern
1	Level and Trend of Solar Activity	General space environment risk evaluation.
2	Solar X-ray Radiation	Solar X-ray radiation is the widely used indicator for solar activity level and flare and associating disturbance harmful for space systems.
3	Solar High Energy Particle	Onboard computer malfunction due to upset of semiconductor devices, deterioration of SAP, electric devises, optical sensor etc…
4	Solar Flare and CME	Solar flares and associating CME are a major source of space environment disturbances. Generally, long duration and strong flares are thought to be important for risk evaluation on satellite operation sources of geomagnetic storms
5	Coronal Holes	Coronal holes are a major source of high speed solar wind, which produces geomagnetic storm.

Space weather risks (2/3)

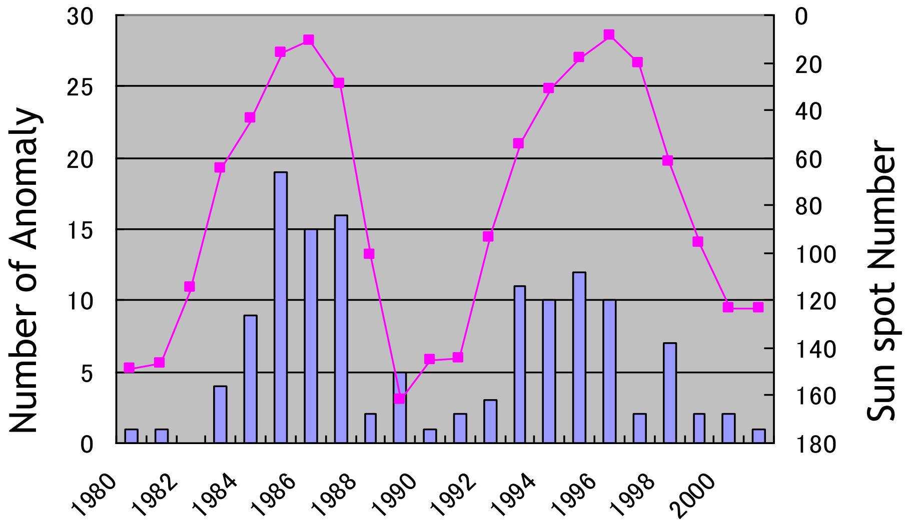
	Item	Influence and concern
6	Galactic Cosmic Rays	Onboard computer malfunction due to upset of semiconductor etc…
7	Solar wind plasma	Geomagnetic storm and Sub-storm caused by high speed wind stream are the potential causes of satellite malfunction.
8	K-index of geomagnetic field	General space environment risk evaluation.
9	Dst-index of geomagnetic field	General space environment risk evaluation.
10	Low energy electrons at GEO	KeV electron is considered major driver of satellite surface charging and following discharging. The surface charging and discharging is one of the major cause of GOE satellite malfunction.
11	High energy electrons at GEO	High energy (>MeV) electron is considered a major driver of satellite charging and following discharging including component and harness inside spacecraft.The charging and discharging is one of the major cause of GOE satellite malfunction.

Space weather risks (3/3)

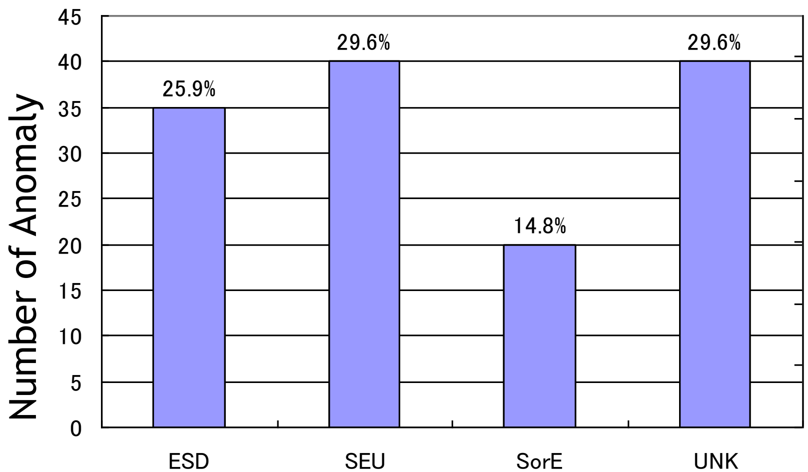
	Item	Influence and concern
12	Low energy electrons at LEO	KeV electron is considered major driver of satellite surface charging and following discharging. The surface charging and discharging is one of the major causes of LEO satellite malfunction.
13	High energy protons at SAA	Onboard computer malfunction due to upset of semiconductor devices, deterioration of SAP, electric devises, optical sensor etc…
14	Solar EUV proxy index	The proxy called f10.7 is used as solar EUV proxy parameter to deduce satellite drag on satellite orbital analysis. Abrupt increase of the proxy may cause severe trouble due to drastic changes of satellite drag.
15	Auroral Electro jet index	The AE is used to atmospheric density model, which leads to satellite drag on satellite orbital analysis. Abrupt increase of AE may cause severe trouble due to drastic change of satellite drag.
16	Ionospheric Disturbances	Operation of satellite at various altitude and ground communications by using radio waves are influenced by the ionospheric condition.

Space Environment Effects on Satellites

Environment	Effects
Vacuum	Contamination
Neutral	Aerodynamic drag Atomic oxygen attack
Plasma	Spacecraft charging Electrostatic discharge
Radiation	Internal charging Total Dose Effects Single Event Effects
Micrometeoroid/ Orbital Debris	Hypervelocity Impacts



One example is given by JAXA. Electro static discharge and single event upset are two major causes of satellite anomaly.

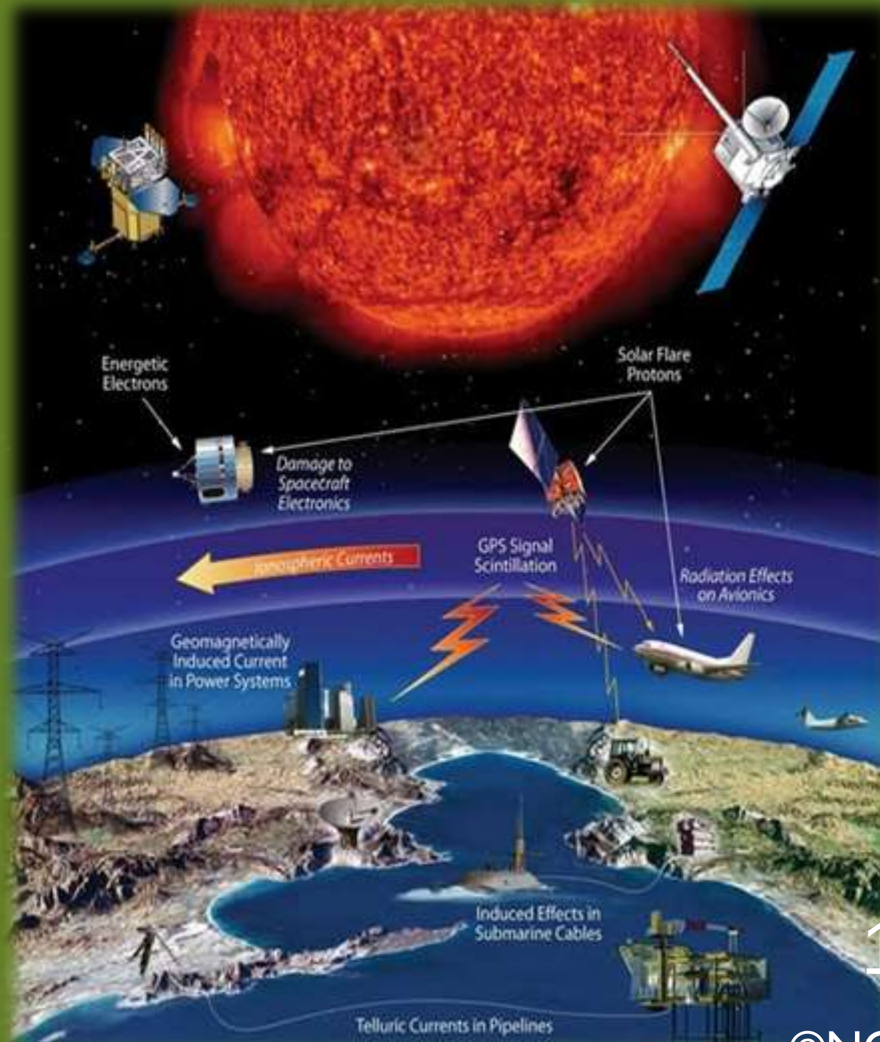


Outline of the presentation

1. Risks of Space Weather
2. Space Weather Guideline
3. Space Weather Forecast
4. Monitoring of Space Weather

Space Weather has a wide range of impacts on terrestrial and space-based infrastructure.

International co-ordination and collaboration is critical for ***long-term sustainability of outer space activities*** .



For the long-term sustainability of outer space activities, dedicated working group (WG) was established from 2011 to 2016.

Expert Group on space weather

-> to contribute long-term sustainability working group by doing tasks to provide a report based on the survey of current practice and procedure and a set of guide lines which would contain the ways to reduce space weather risks and technical standards.

23 States joined

Scope of the **Expert Group** (after ToR)

i) Collection, sharing and dissemination of data, model and forecast tool

ii) Capabilities to provide a comprehensive and sustainable network of sources of key data in order to observe and measure phenomena related to space weather in real time or near-real time

iii) Open sharing of established practices and guidelines to mitigate the impact of space weather phenomena on operational systems

iv) Coordination among State on ground-based and space-based space weather observations in order to safeguard space activities.

Methodology – time line (after ToR)

Year	2012			2013			2014	
Month	2	6	10	2	6	10	2	6
Space Weather Expert Group Meeting	△	△	△	△	△	△	△	△
Expert Group Repot	*Out Line*	*I-st draft*	*2-nd draft*	***Final Report***				
Guide Line Paper				*Out Line*	*I-st draft*	*2-nd draft*	***Final Report***	

Final Report from Expert group

(A/AC.105/C.1/2014/CRP.15E *UN COPUOS, 2014*)

- i) Chap.1 Executive summary
- ii) Chap.2 Introduction
- iii) Chap.3 Identification of risks from space weather
- iv) Chap.4 Current practices and procedures
  - ・Observations, models, tools for space weather prediction,
  - ・Comprehensive network space weather services,
  - ・Engineering approaches to mitigate space environment effects,
- v) Chap.5 Coordination among States on data and services to safeguard space activities
- vi) Chap.6 Guidelines for space actors
  - ・Recommended guidelines for the long-term sustainability of space activities.

Essence of Space Weather Guidelines for the Long-Term Sustainability of Outer Space Activity

1) Space actors, member states and their national and international agencies, should ***support and promote the collection, sharing, inter-calibration and dissemination of critical space weather data.***

2) Member States and their national and international agencies should ***support and promote further coordinated development of advanced space weather models and forecast tools in support of identified user needs.***

3) Member States and their national and international agencies should ***support and promote the sharing and dissemination of space weather model outputs and forecasts.***

4) Member States and their national and international agencies should ***support and promote the collection, sharing, dissemination and access to information relating best practices for mitigating the effects of space weather on ground- and space-based systems and related risk assessments*.**

Proposed Recommendations

1: **Develop a basis for the coordination of ground and space based infrastructure** to ensure the long term continuity of critical space weather observations.

2: Provide a mechanism for the coordination of ground and space based infrastructure to ensure the long term continuity of critical space weather observations.

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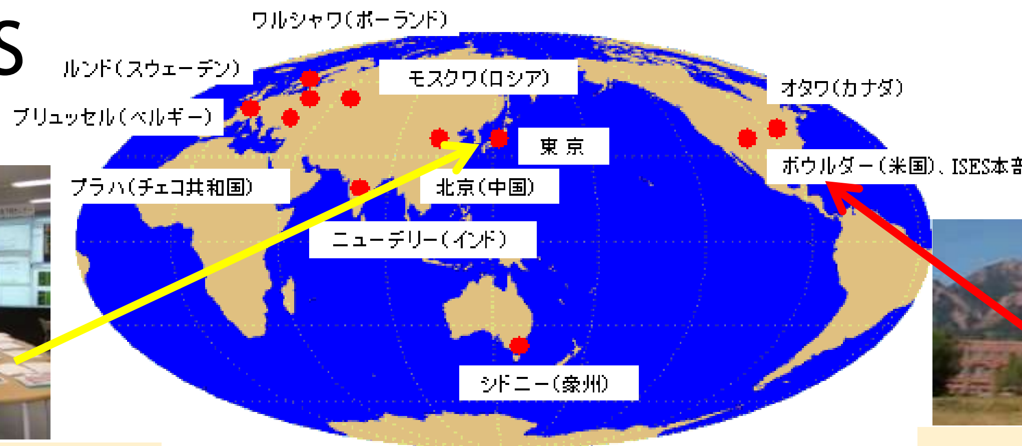
Efforts to achieve better space weather forecasts

ISES



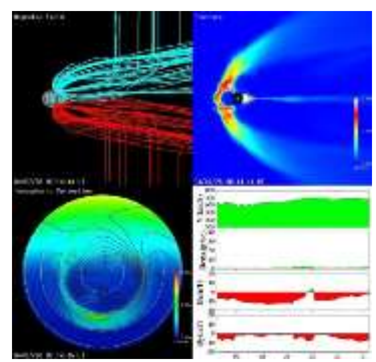
Prediction Items
- Solar activity
- Solar protons
- Magnetic activity

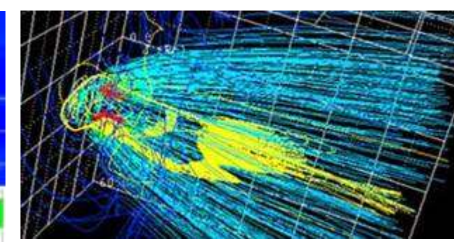
Space Weather Prediction Center in Japan（NICT ）

NOAA Space Weather Prediction Center (ISES HQ)

Solar Radio Observation

Satellite Data Reception





Real time simulation of magnetosphere

Space weather forecast (1/1)

	Item	Forecast
1	Sunspot	
2	Coronal hoes	
3	Flare/CME	*ISES/Flare forecast
4	Solar proton	*ISES/Solar proton forecast
5	Solar wind	Solar wind models
6	Geomagnetic field disturbance (Dst)	*ISES/Storm forecast
7	Geomagnetic field disturbance (AE)	*ISES/Substorm forecast
8	Radiation belt	Radiation belt models
9	Aurora	Aororal oval prediction models
10	Ionosphere	Ionosphere models
11	Radio wave propagation	Disturbance models

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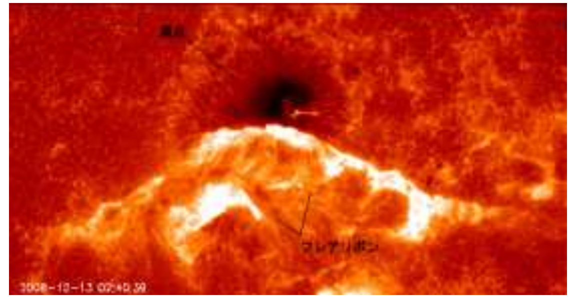
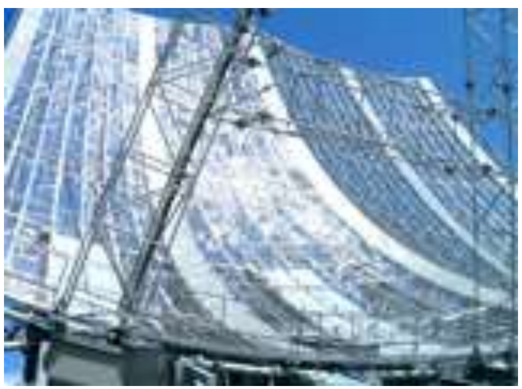
Space weather monitoring in Japan

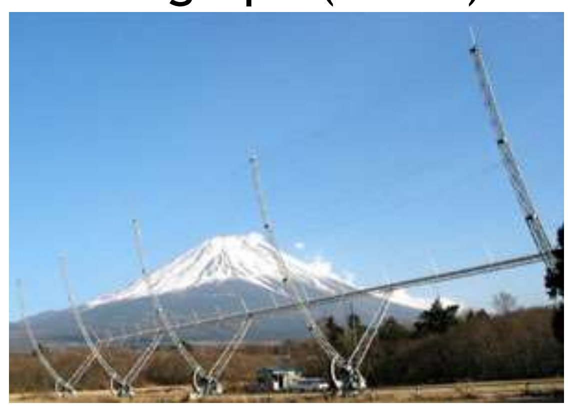
Hinode satellite
(JAXA/NAOJ)





Solar Radio Burst
(Tohoku Univ.)

Heliograph (NAOJ)



IPS (STEL/Nagoya Univ.)

Hida Observatory
(Kyoto Univ.)

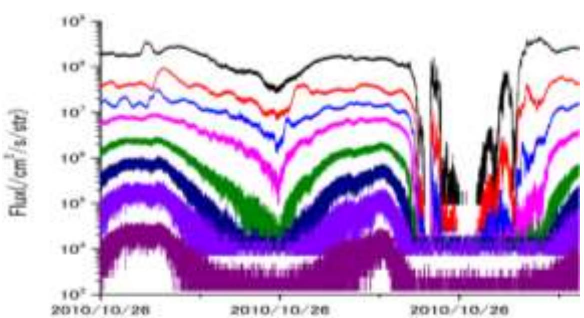
Muon (Shinsyu Univ.)

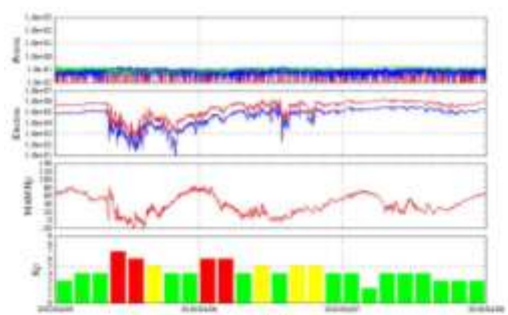
Space weather monitoring in Japan

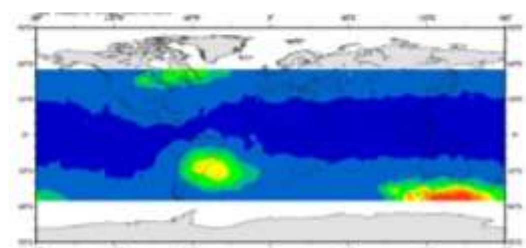
'Space Environment Now cast' by JAXA

Satellite Name	Launch Data (Altitude)	Type
ETS-V	1987.8 (36000km)	GEO
ETS-VI	1994.8 (8000～38000km)	GTO
ADEOS	1996.8 (800km)	LEO
ETS-VII	1997.11 (500km)	LEO
STS-89	1998.1 (300km)	LEO
ISS	2001 (400km)	LEO
MDS-1	2002.2 (250～36000km)	GTO
DRTS	2002.9 (36000km) ＊	GEO
ADEOS-II	2002.12 (800km)	LEO
ALOS	2006.1 (700km)	LEO
ETS-VIII	2006.12 (36000km) ＊	GEO
Jason-2/3	2008.6 (1336km) ＊	LEO
GOSAT	2009.1 (700km) ＊	LEO
JEM/SEDA-AP	2009.5 (400km) ＊	LEO
QZS	2010 (Quasi Zanies Orbit) ＊	QZO

Real time plots are being provided by JAXA.



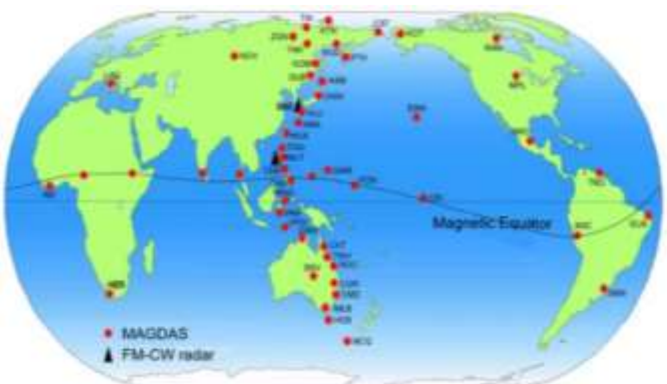




Space weather monitoring in Japan

JAXA/ISAS satellites

HF radar
(STEL/Nagoya Univ.
NIPR, NICT)



Magnetometer chain
/MAGDAS(Kyushu Univ.)

All-sky imager
(STEL/Nagoya Univ., NICT)

5 World Data Centers in Japan

Space weather monitoring (1/2)

	Item	Measurement in Japan (for example)
1	Level and Trend of Solar Activity	f10.7 radio index (NICT)
2	Solar X-ray Radiation	None
3	Solar High Energy Particle	In-situ measurement by satellite sensor (JAXA)
4	Solar Flare and CME	Ground-base observation (NICT)
5	Coronal Holes	Remote measurement by satellite sensor (JAXA)
6	Galactic Cosmic Rays	Measurement by satellite sensor (JAXA)
7	Solar wind plasma	Measurement by satellite sensor (JAXA)
8	K-index of geomagnetic field	Ground based magnetometer observation network and its real-time data circulation (Kyushu Univ)
9	Dst-index of geomagnetic field	Ground based magnetometer observation network and its real-time data circulation (Kyushu Univ)
10	Low energy electrons at GEO	None

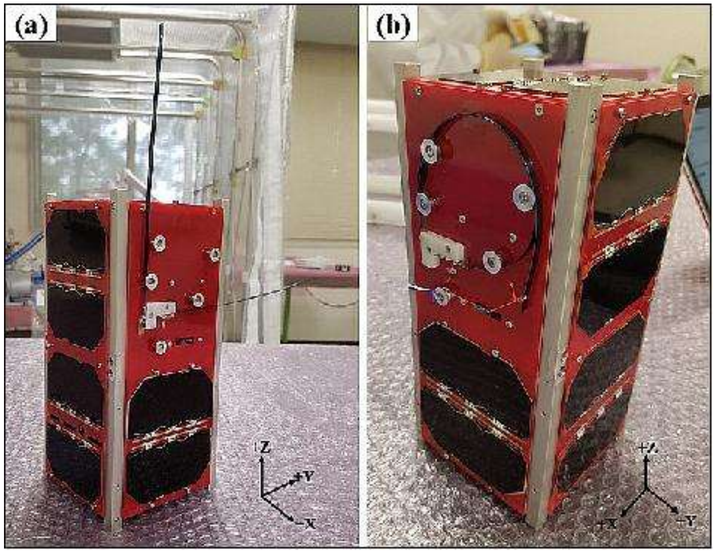
Space weather monitoring (2/2)

	Item	Measurement in Japan (for example)
11	High energy electrons at GEO	In-situ measurement by satellite sensor (JAXA)
12	Low energy electrons at LEO	None
13	High energy protons at SAA	In-situ measurement by satellite sensor (JAXA)
14	Solar EUV proxy index	None
15	Auroral Electro jet current	Ground based magnetometer observation network and its real-time data circulation (Kyushu Univ)
16	Ionospheric current disturbances	Ground based magnetometer observation network and its real-time data circulation (Kyushu Univ)

Outline of the presentation

1. Risks of Space Weather
2. Space Weather Guideline
3. Space Weather Forecast
4. Monitoring of Space Weather
5. Use of Micro/Small-Sat

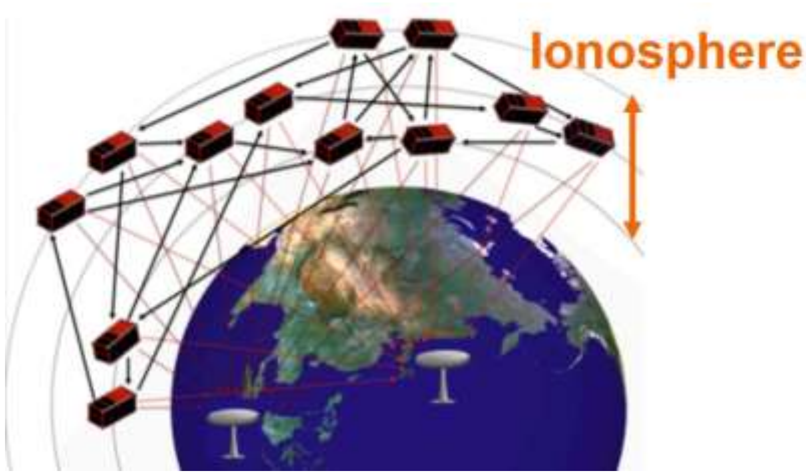
Scientific Approach to collect Space Weather Key Data



SPATIUM I and SPATIUM II

One ultra-small satellite ("CubeSat“, shown above); SPATIUM 1 was successfully deployed on October 6, 2018, from the Japanese Experiment Module "Kibo“. SPATIUM II will be launched later this year.
SPATIUM I and SPATIUM II are developed at Kyutech and are focused on measuring TEC (Total Electron Content) in the ionosphere.

SPATIUM Project of Kyutech



Overview of SPATIUM project

CSAC (Chip-Scale Atomic Clock)

The ultimate goal of the SPATIUM project is the observation of the ionosphere by a constellation of CubeSats.
SPATIUM I and SPATIUM II have installed Chip-Scale Atomic Clock (CSAC) as the precision clock to permit the measurement of TEC in the ionosphere.
SPATIUM I demonstrated the accuracy and feasibility of CSAC on-orbit.
SPATIUM II will demonstrate point-to-point measurements of TEC.

Scientific Approach to collect Space Weather Key Data

	Item	Measurement in Japan (for example)
1	Solar X-ray Imaging	None
2	Solar High Energy Particle	In-situ measurement by satellite sensor (JAXA)
3	Galactic Cosmic Rays	Measurement by satellite sensor (JAXA)
4	Low energy electrons at GEO	In-situ measurement by satellite sensor (NiCT)
5	High energy electrons at GEO	In-situ measurement by satellite sensor (NiCT)
6	Low energy electrons at LEO	None
7	High energy protons at LEO	In-situ measurement by satellite sensor (JAXA)

Let's consider small satellite projects for collecting Space Weather Data