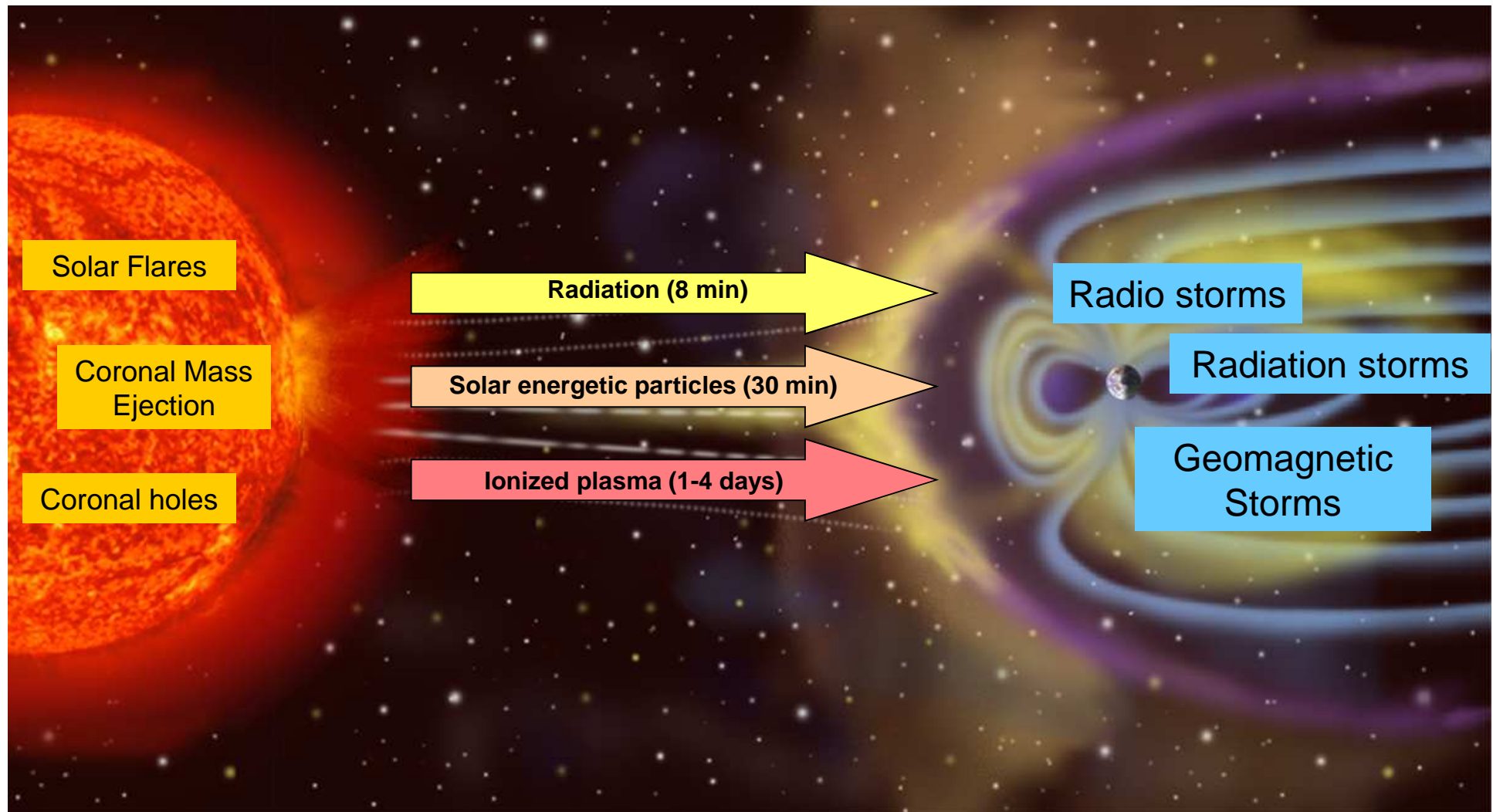


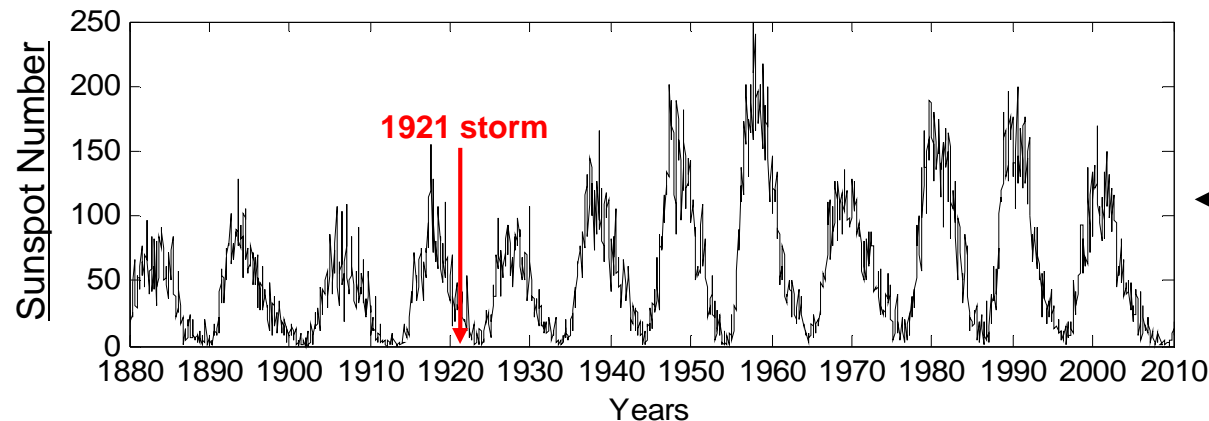
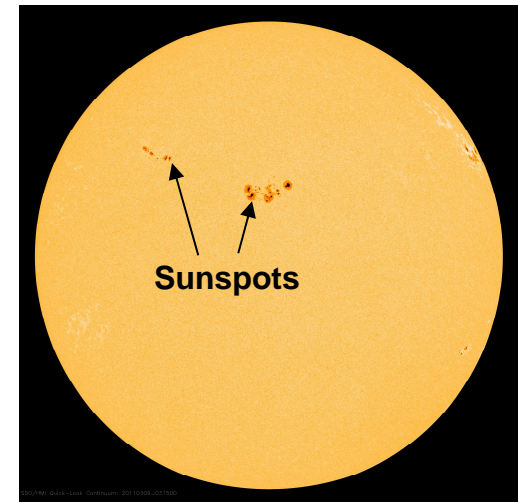
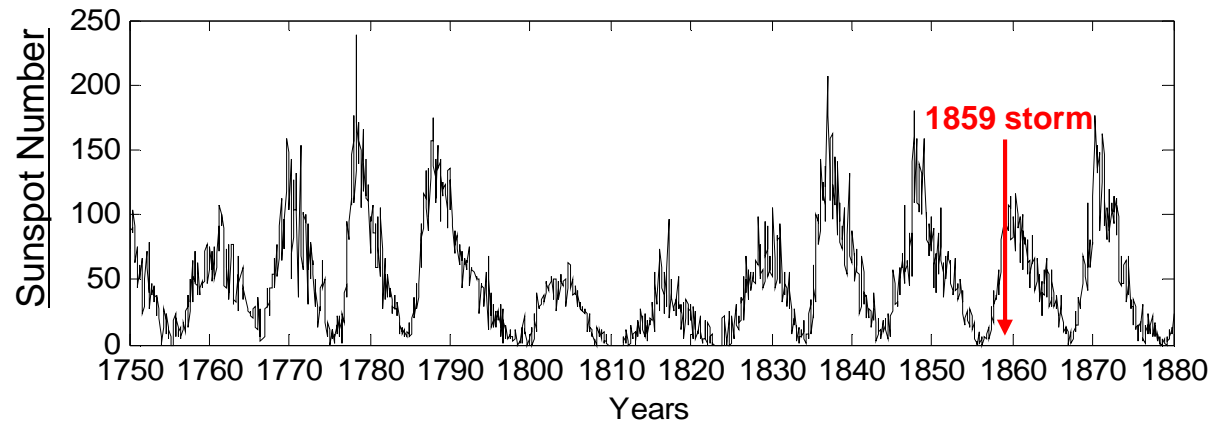
Space Weather and its impact on the infrastructure / aviation

Space weather workshop – Köln, March 20th, 2013
Emilien ROBERT

Introduction to Space Weather



Sunspot and the Solar Cycle

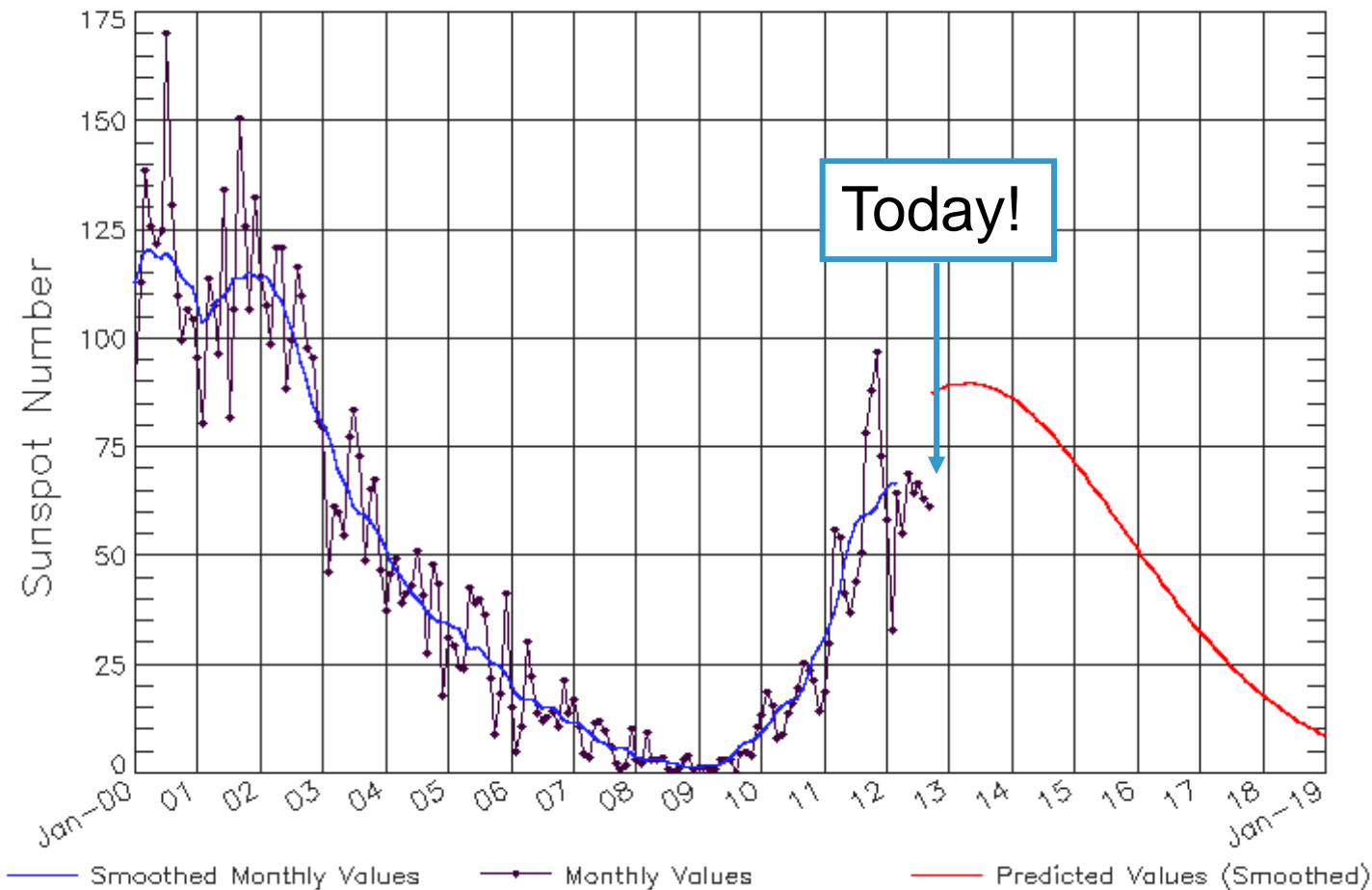


← Solar cycle ~11 years

- Solar eruptions are most likely to occur during high solar activity or during the solar activity decrease
- Severity of solar eruptions are not linked to the magnitude of the solar cycle

Next period of high solar activity

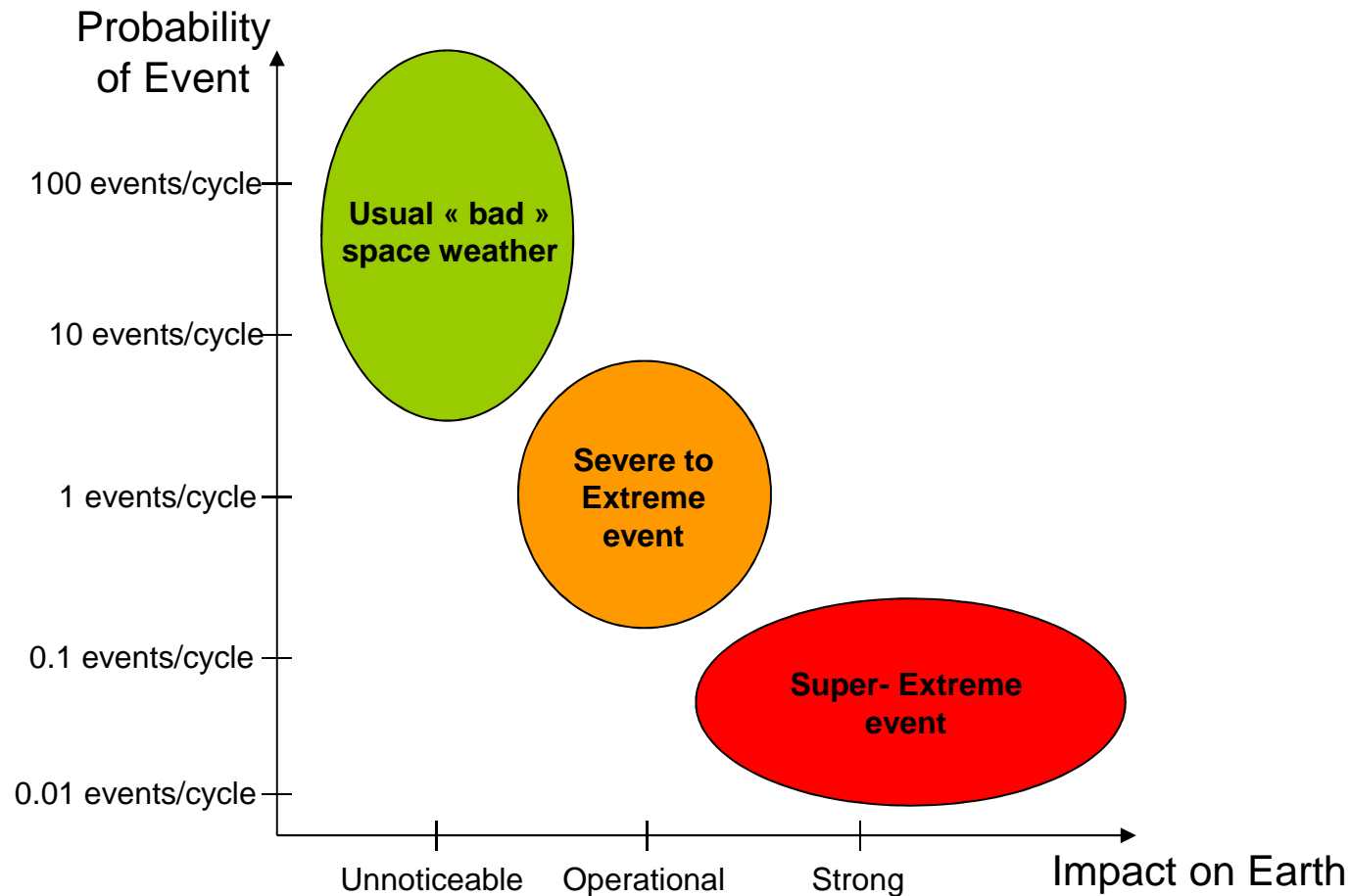
ISES Solar Cycle Sunspot Number Progression
Observed data through Sep 2012



Updated 2012 Oct 8

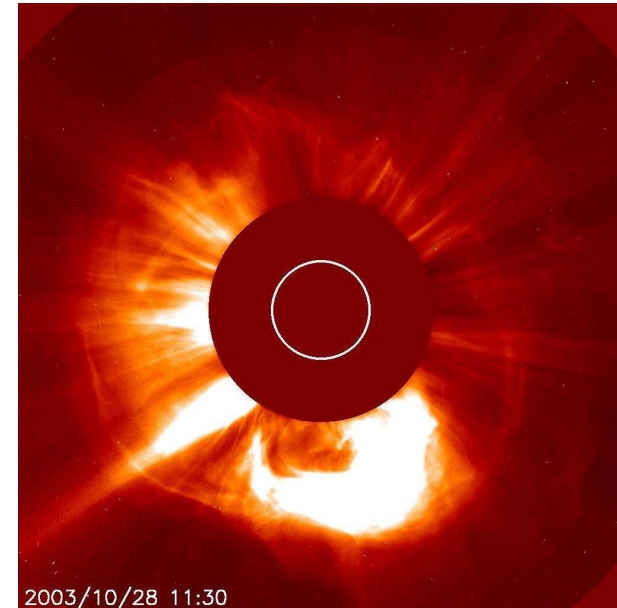
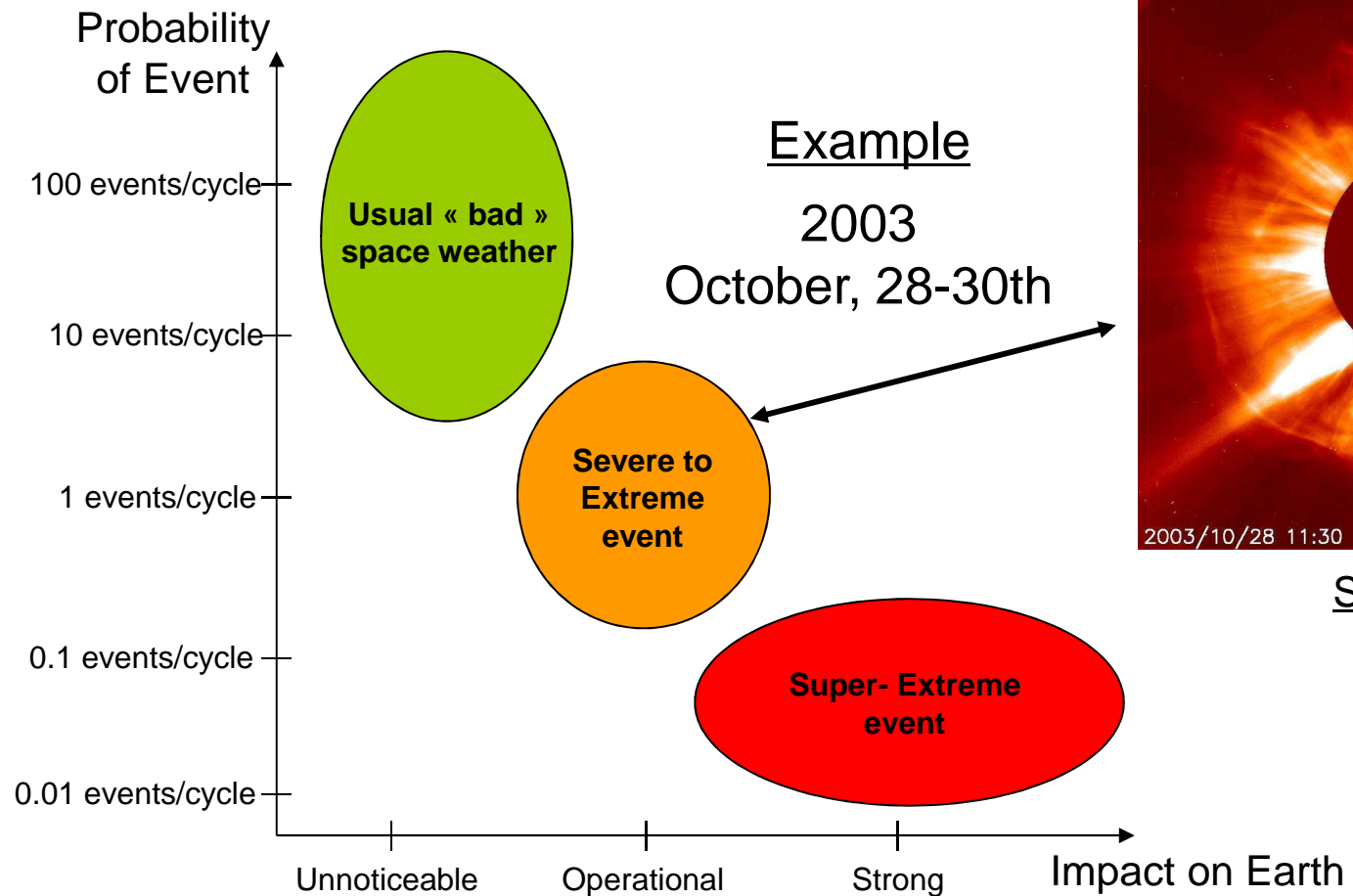
NOAA/SWPC Boulder, CO USA

Magnitude/Probability of Solar Event



Nota: Solar cycle~11 years

Magnitude/Probability of Solar Event



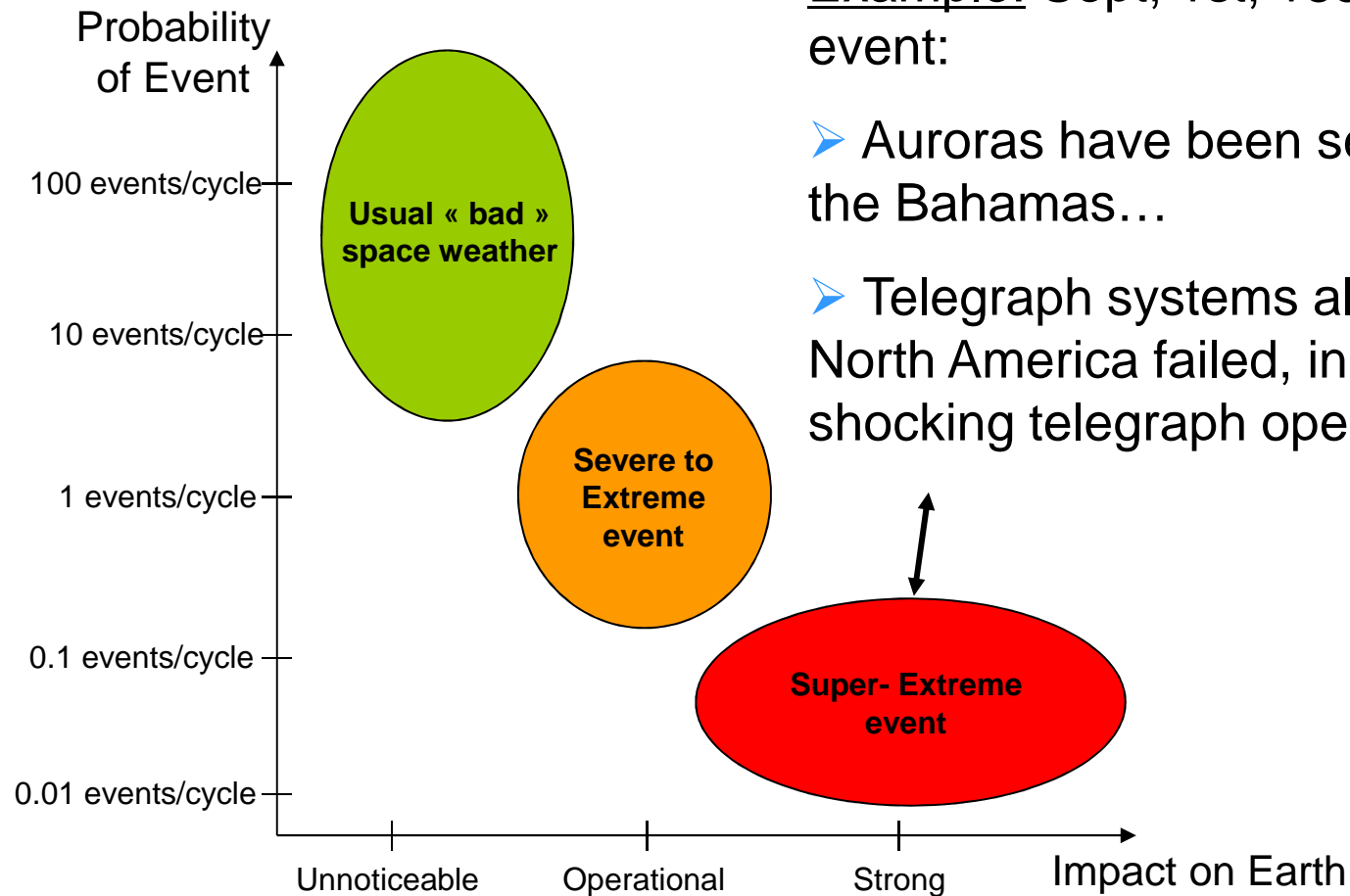
Solar eruption

Nota: Solar cycle~11 years

Magnitude/Probability of Solar Event

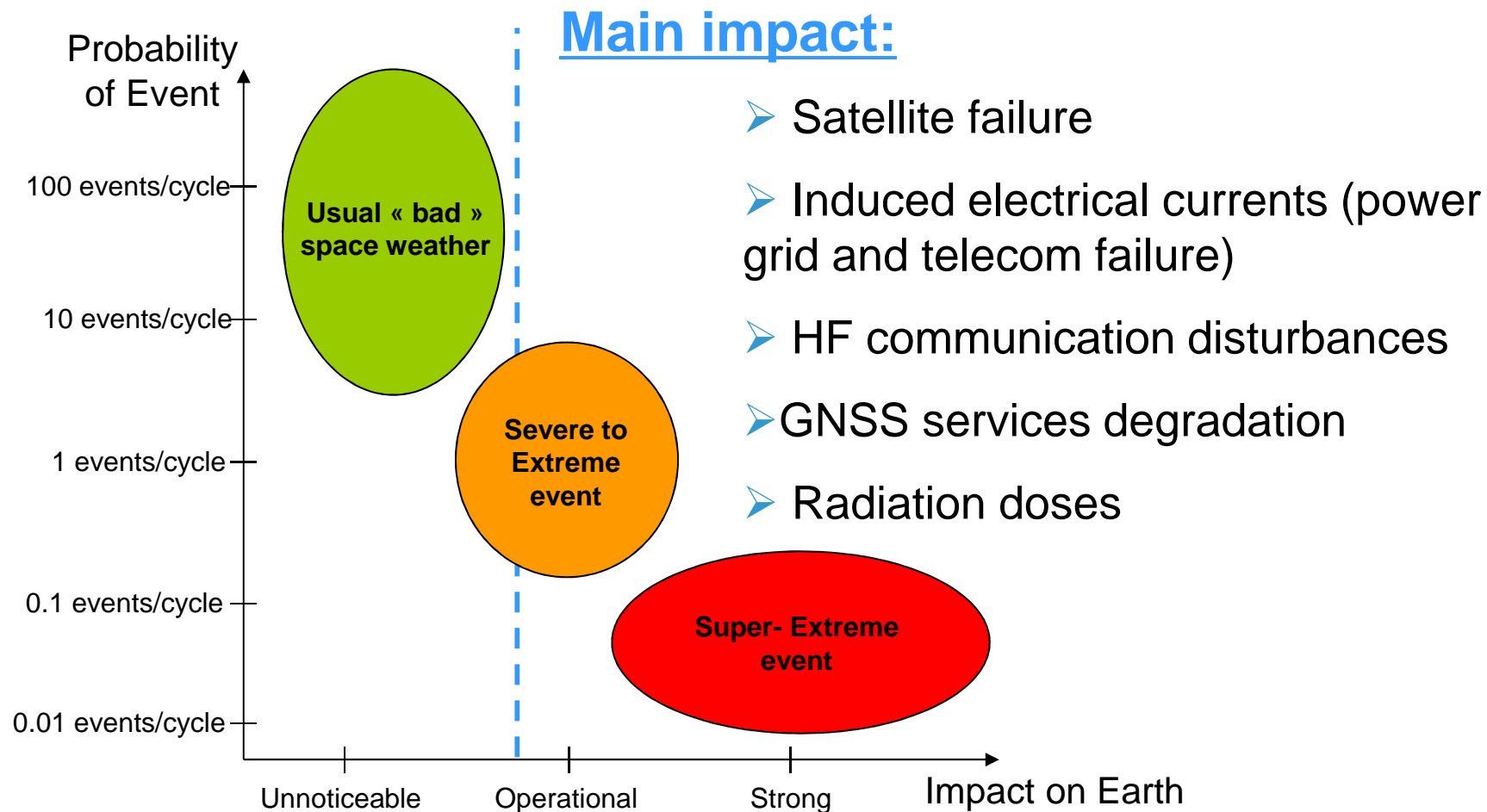
Example: Sept, 1st, 1859 «Carrington» event:

- Auroras have been seen down to Cuba, the Bahamas...
- Telegraph systems all over Europe and North America failed, in some cases even shocking telegraph operators.



Nota: Solar cycle~11 years

Magnitude/Probability of Solar Event



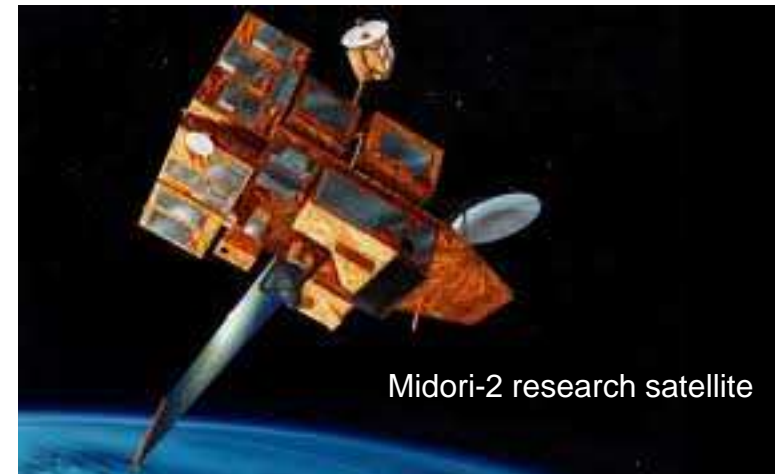
Nota: Solar cycle~11 years

Space Weather impact on satellites

- Solar Energetic Particles and geomagnetic storm may cause failure on satellite

- Example:

- 4 US Navy navigational satellites lost on March 1989.
- \$450 million Midori-2 research satellite lost on October 2003 “Halloween storm”



- Possible impact:

- Severe to extreme event: a couple of space vehicles may be lost
- Super-extreme event: up to 50% of the space vehicles may be lost

- Mitigations:

- Back up to satellite navigation and communication (HF/VHF, ground based navigation, radar vectoring, inertial navigation...)

Space Weather impact on power supply

➤ Geomagnetic storm may create failure in power and ground telecommunication grid

➤ Example: On March 13th, 1989, at 2:45 AM, the entire Quebec power grid collapsed and 6 million people were affected for 9 hours

➤ Possible impact:

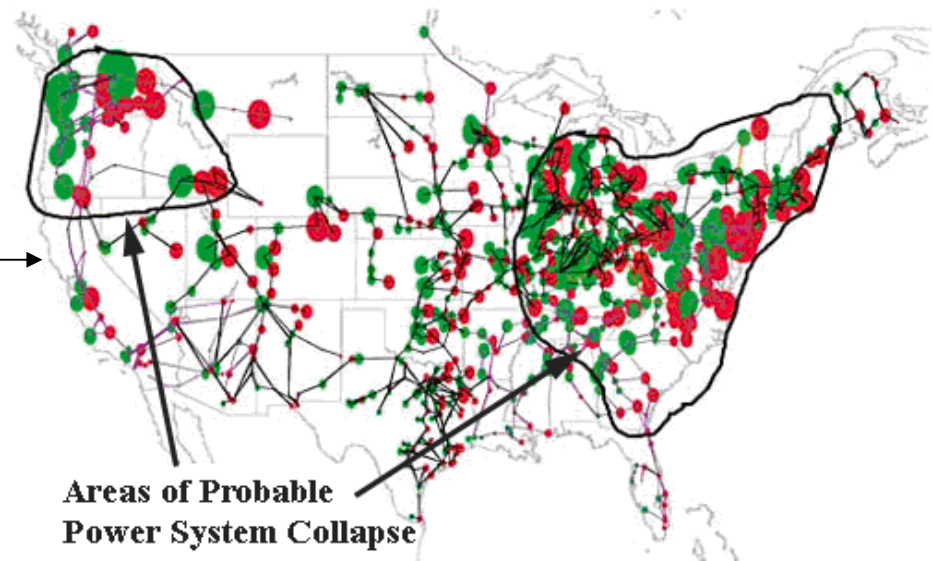
- Severe to extreme event: power failure over part of a country for tens of hours
- Super-extreme event: power failure over part of a continent

➤ Mitigations:

- Alternate power generation



Image courtesy of Public Service Electric and Gas and Peter Balma



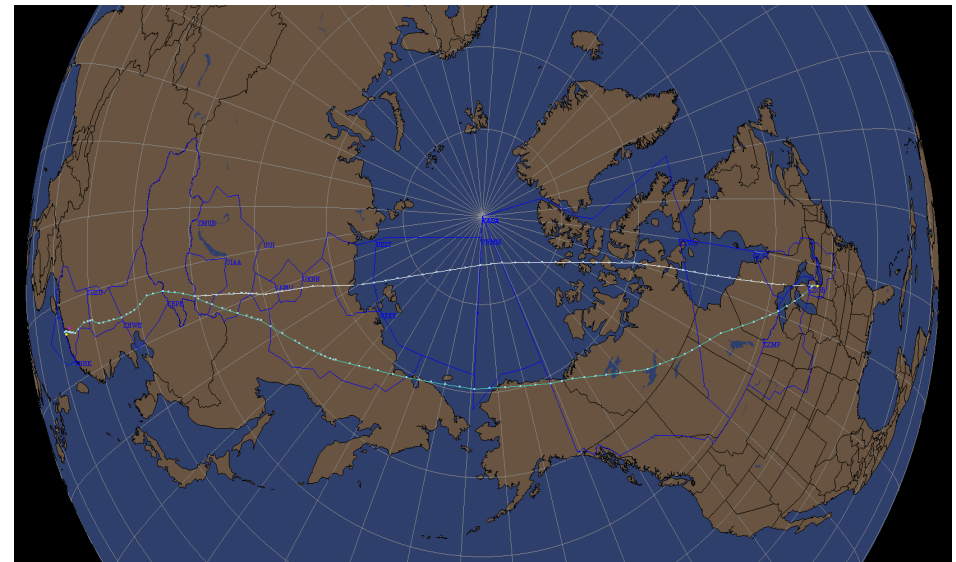
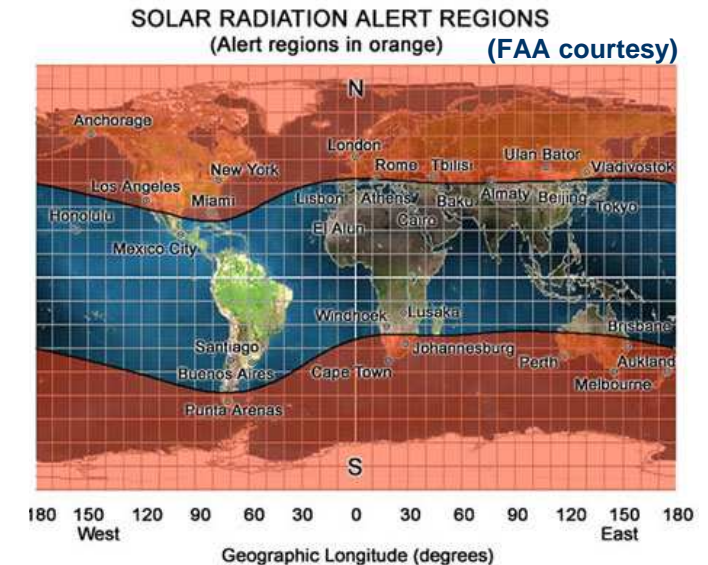
Space Weather impact on communication

- Geomagnetic storm may create failure in the ground communication network and in air HF communication
- Example: On September 7th, 2005, solar activity severely impacted all HF communications over US.
- Possible impact:
 - HF and, potentially, satellite communication may be degraded
- Mitigations:
 - VHF, SATCOM voice communication
 - Operational mitigations based on space weather nowcast / forecast: flights can be re-routed



Radiation dose impact on health and system

- Radiation storm may cause unusually high levels of ionizing radiation
- Radiation storm may also cause failure into electronic devices
- Example:
 - on October, 28th, 2003, FAA Civil Aerospace Medical Institute issued a Solar Radiation Alert
- Possible impact :
 - Higher exposure dose than usual
 - Potential onboard system failure
- Mitigations :
 - Decrease the aircraft altitude and latitude
 - Polar routes may be avoided



Space Weather impact on GNSS

- Geomagnetic storm may cause:
 - error in the GNSS position (ionosphere delay)
 - loss of lock of the satellite (scintillation)

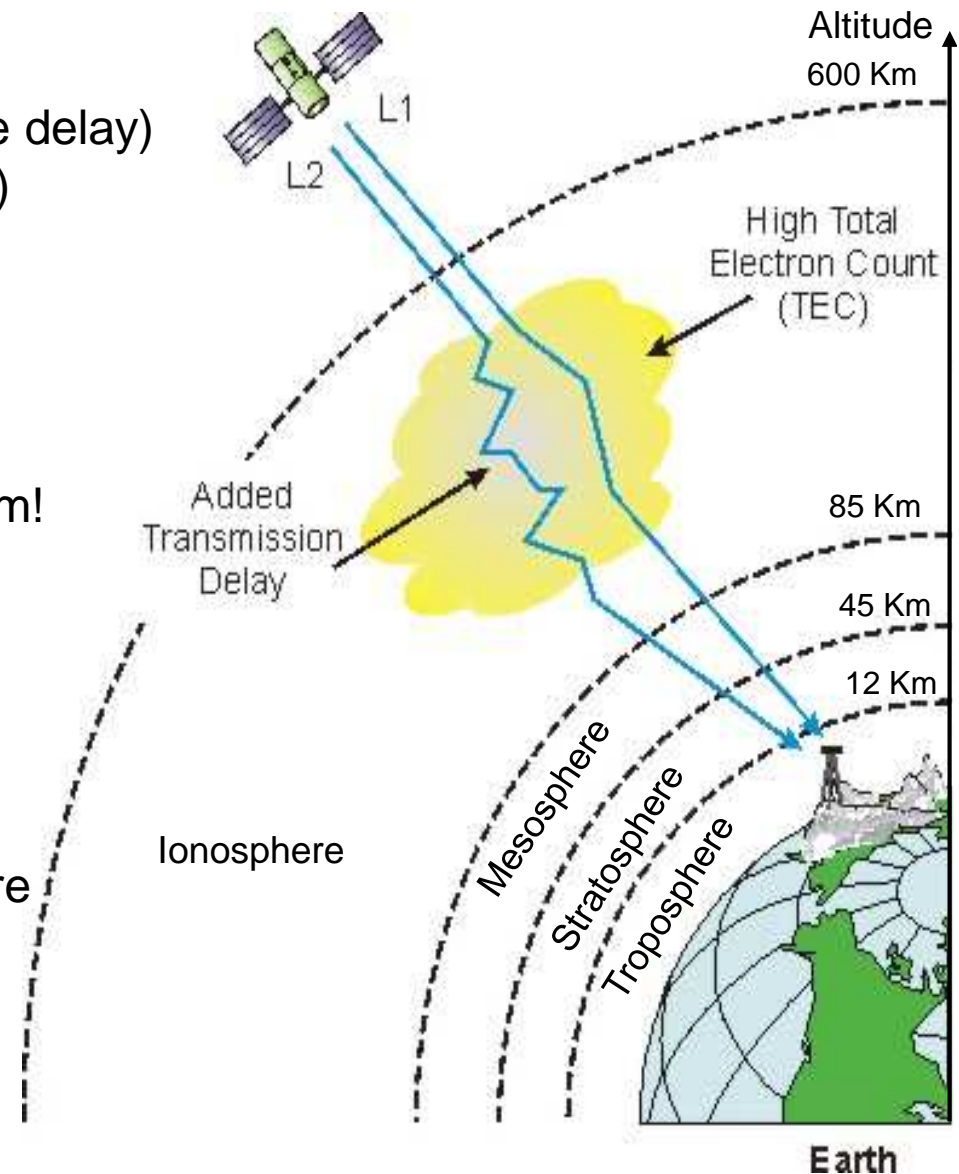
- Possible impact:

- Accuracy decrease
 - Disruption of services

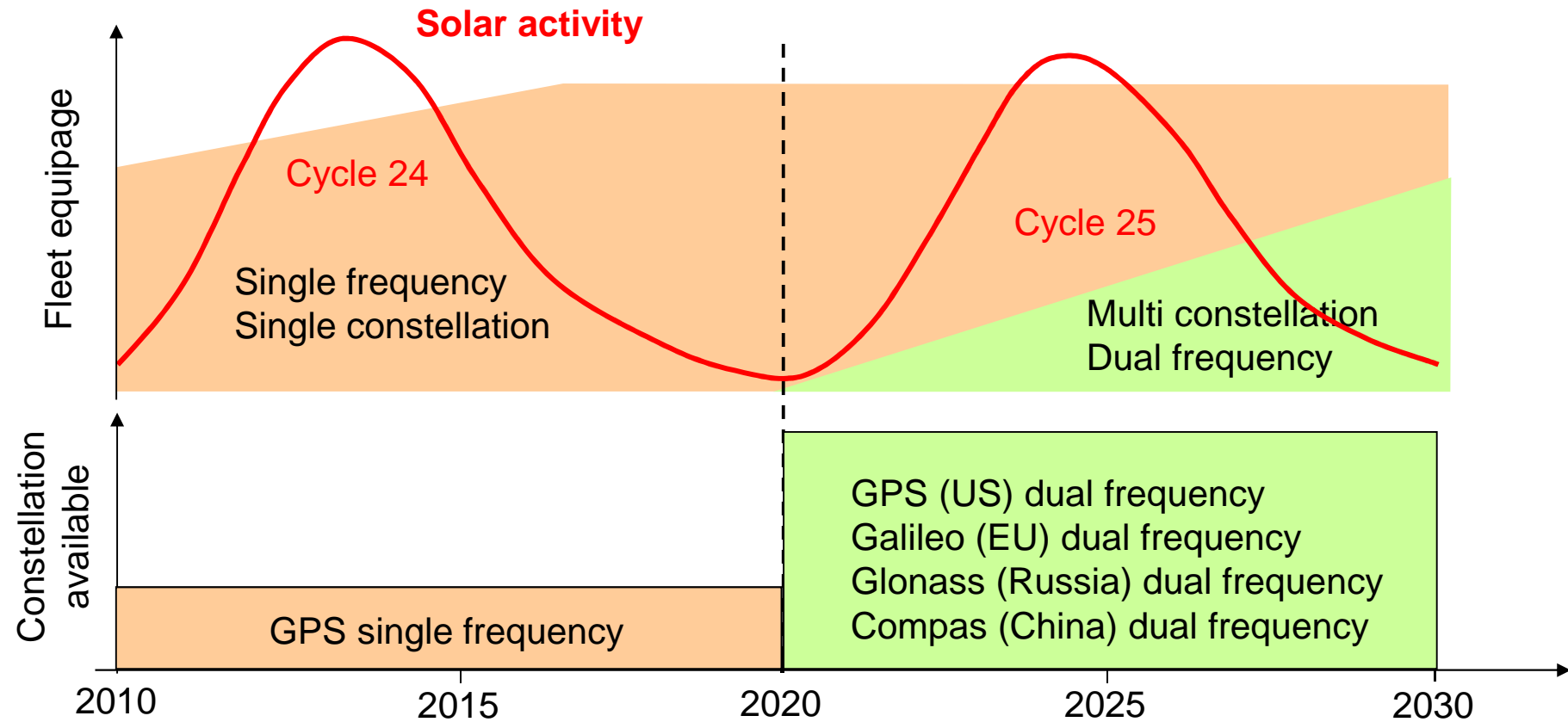
But it depends on the augmentation system!

- Mitigations :

- Use of dual frequency constellation: next GPS (US), Galileo (EU), Glonass (Russia), Compas (China)
 - Use of multi-constellation to have more satellites



GNSS roadmap and fleet equipment

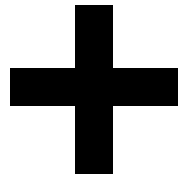


- ⇒ Dual constellation (or more), dual frequency will be operational from 2020 but the A/C fleet will not be significantly equipped for the 25th solar cycle (2022-2027)

Space Weather Impact on GNSS operations

GNSS

GPS
Galileo*
Compas*
Glonass*



* When available: 2020+

Airborne Based Augmentation System

Coverage: Worldwide

Operations:

- En route and terminal navigation
- Non precision approach (LNAV / VNAV)
- GNSS based surveillance applications (ADSB)



Possible impact:

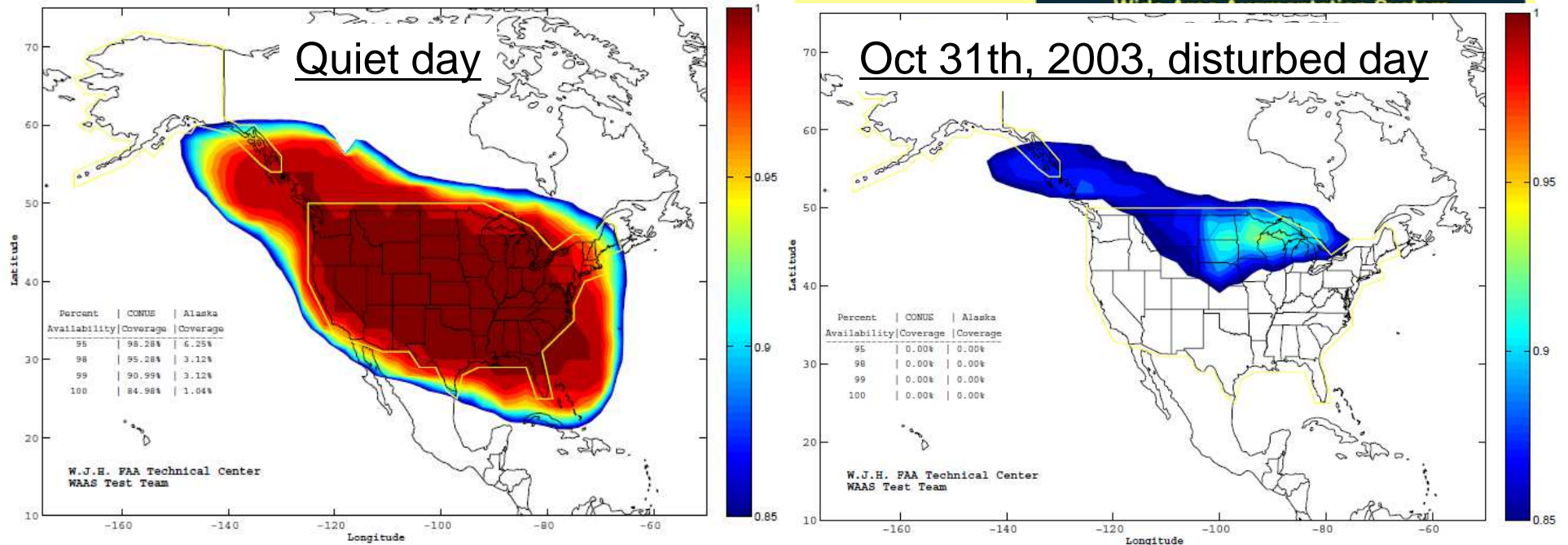
- Accuracy decrease (100s meters)
- Loss of services over a contained (extreme) or worldwide (super-extreme) area (TBC)

Mitigations:

- Back up to satellite navigation & surveillance
- Long term future: multi-constellation & dual-frequency receivers

Space Weather Impact on GNSS operations

Satellite Based Augmentation System



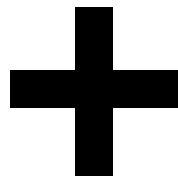
Mitigations:

- Non GNSS based landing system (ILS, MLS...)
- Short/Mid term future: system improvement
- Long term future: dual frequency constellation (TBC)

Space Weather Impact on GNSS operations

GNSS

GPS
Galileo*
Compass*
Glonass*



* When available: 2020+

Ground Based Augmentation System

Coverage: Local (airport)

Operations:

- Precision approach (CAT I – II/III)

Possible impact:

- Positioning error higher than usual
- Regional loss of services

Mitigations:

- Non GNSS based landing system (ILS, MLS)
- Use of space weather nowcast/forecast (Australia)
- Long term future: dual frequency constellation (TBC)



Eurocontrol involvement in space weather

➤ Directorate SESAR and Research

- SESAR WP 15.03.04 task 6: GNSS vulnerability
 - ↳ Task 6.a: Ionosphere assessment impact



➤ Directorate Network Management

- European Aviation Crisis Coordination Cell (EACCC) has identified the space weather as a possible hazard for aviation.



Network Manager
nominated by
the European Commission



➤ FAA-EUROCONTROL Memorandum of Cooperation

- includes space weather as an area of mutual interest and coordination. ICAO space weather activities are followed up under this working arrangement.



**Federal Aviation
Administration**



ESA website

<http://www.esa-spaceweather.net/>

General public website

<http://spaceweather.com>

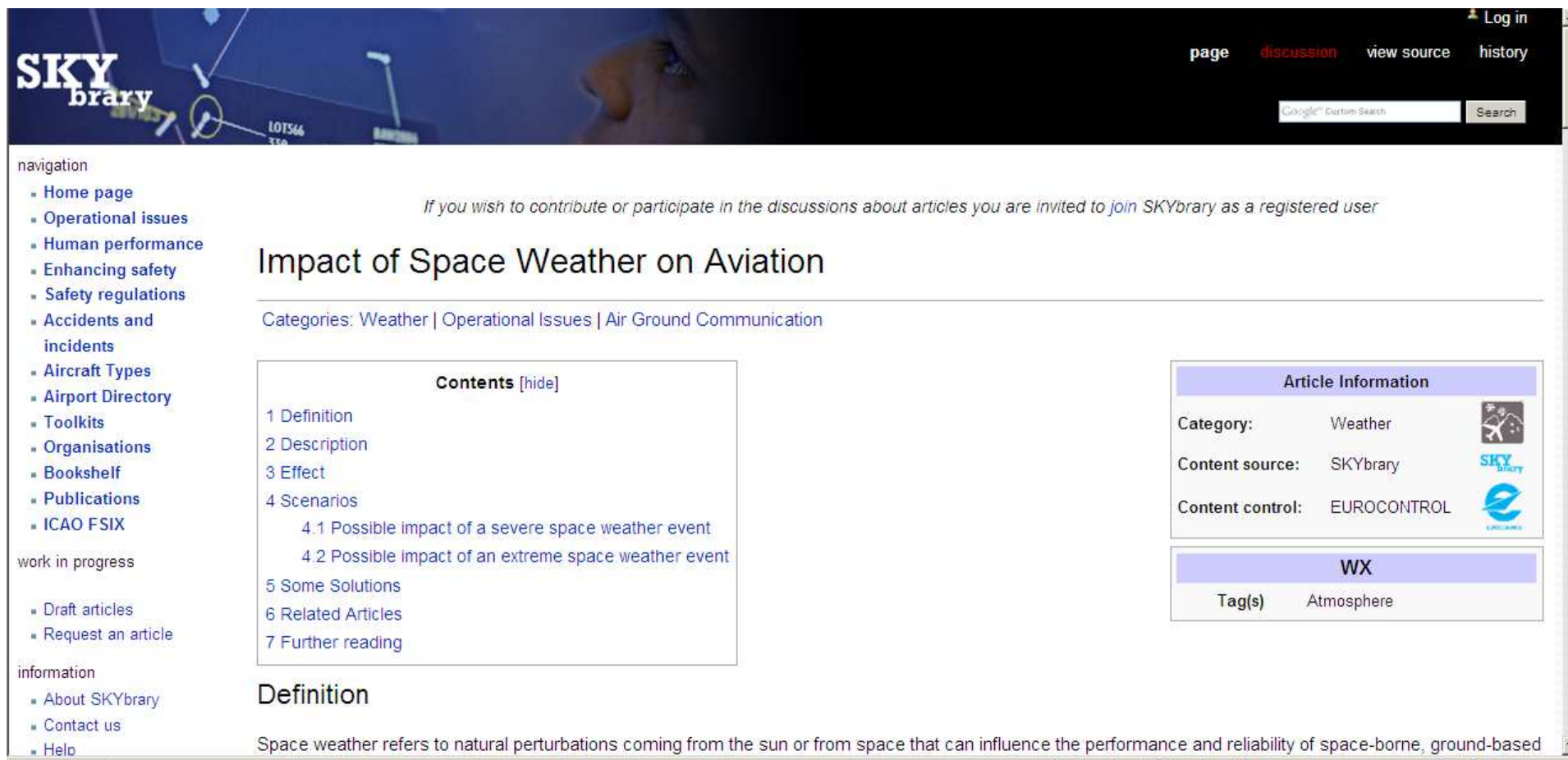
NOAA website

<http://www.swpc.noaa.gov/>

Current Space Weather Conditions

<http://www.swpc.noaa.gov/aviation/>

More information? SKYBRARY!!



The screenshot shows the SKYbrary website interface. At the top, there's a navigation bar with links for 'page', 'discussion', 'view source', and 'history'. A search bar is also present. Below the header, a sidebar on the left contains a 'navigation' menu with links like 'Home page', 'Operational issues', 'Human performance', 'Enhancing safety', 'Safety regulations', 'Accidents and incidents', 'Aircraft Types', 'Airport Directory', 'Toolkits', 'Organisations', 'Bookshelf', 'Publications', and 'ICAO FSIX'. There's also a 'work in progress' section with 'Draft articles' and 'Request an article', and an 'information' section with 'About SKYbrary', 'Contact us', and 'Help'.

The main content area features the article title 'Impact of Space Weather on Aviation' with a sub-header 'Categories: Weather | Operational Issues | Air Ground Communication'. Below the title is a 'Contents [hide]' box listing sections: 1 Definition, 2 Description, 3 Effect, 4 Scenarios (with sub-items 4.1 and 4.2), 5 Some Solutions, 6 Related Articles, and 7 Further reading. To the right of the article is an 'Article Information' box showing 'Category: Weather', 'Content source: SKYbrary', and 'Content control: EUROCONTROL'. Below that is a 'WX' box with 'Tag(s) Atmosphere'.

The article text begins with the 'Definition' section, stating: 'Space weather refers to natural perturbations coming from the sun or from space that can influence the performance and reliability of space-borne, ground-based'.

<http://www.skybrary.aero/index.php/Impact of Space Weather on Aviation>