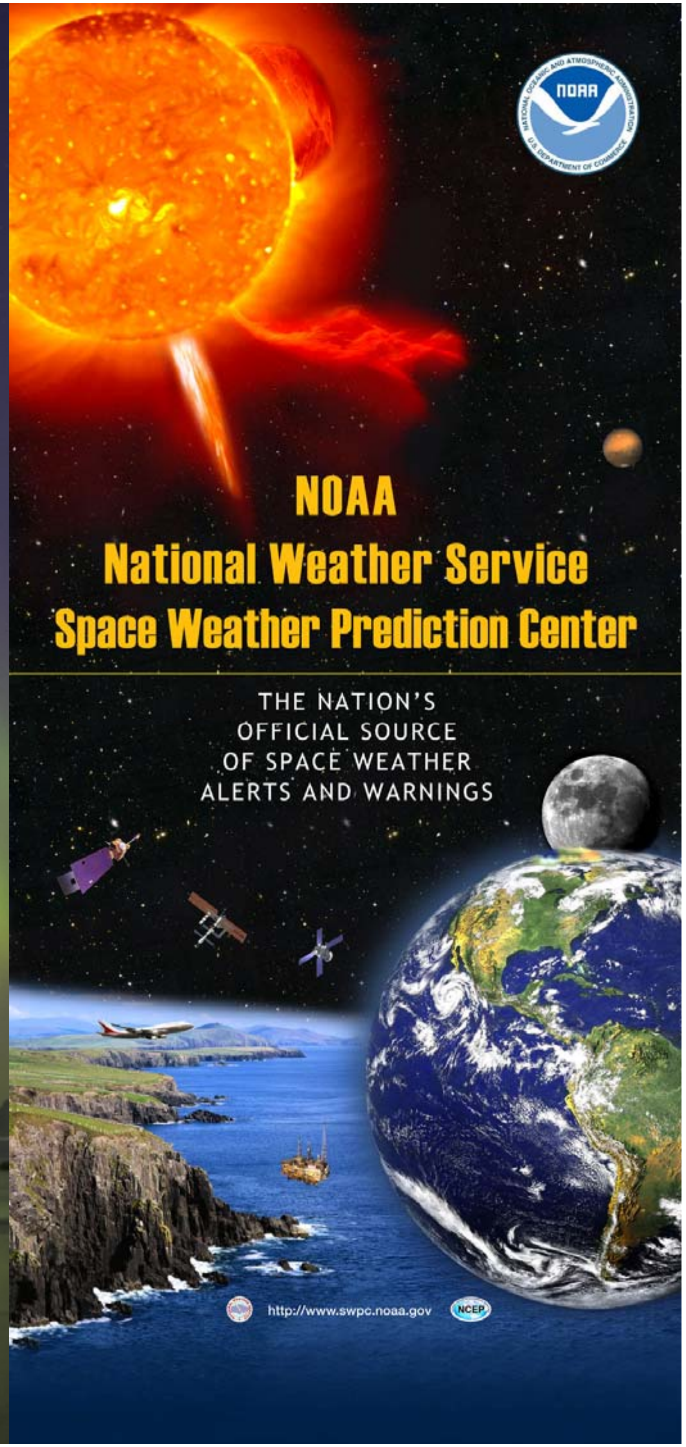
Space Weather Impacts on Aviation Systems

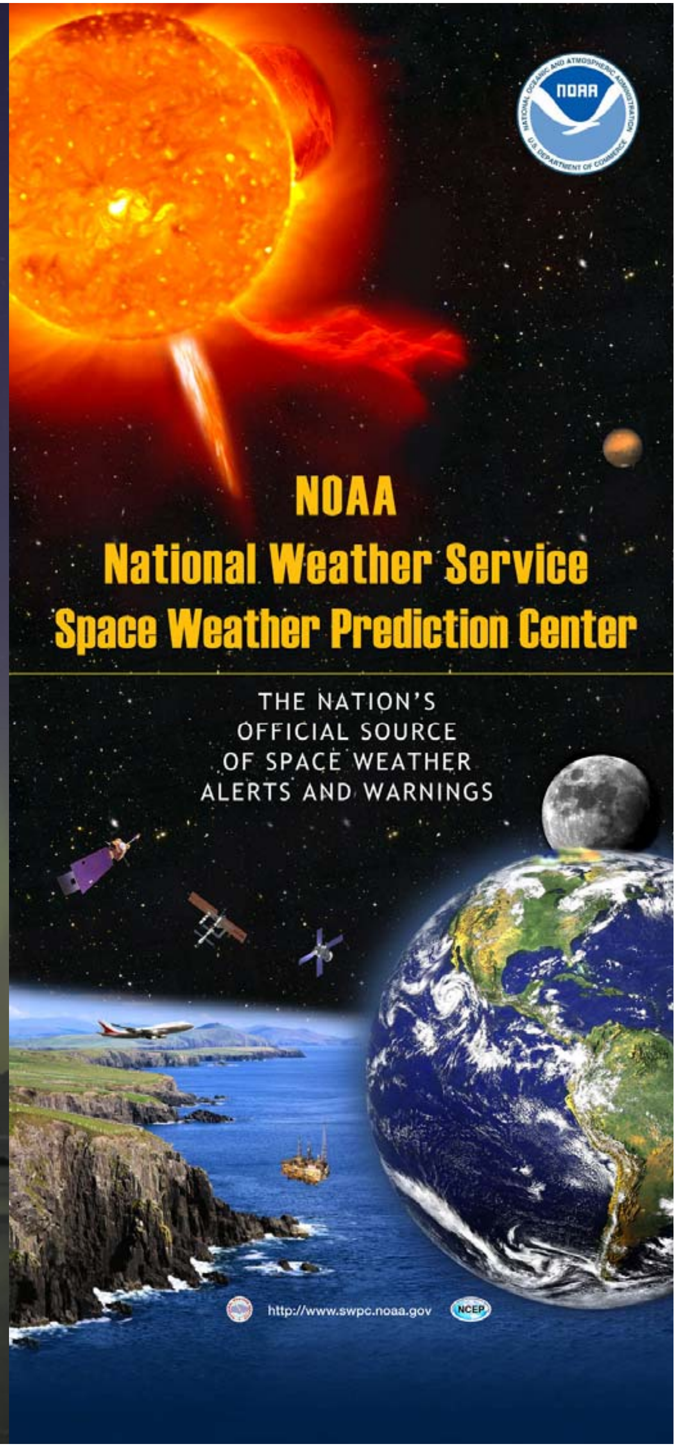
Bill Murtagh
NOAA Space Weather Prediction Center
Boulder, Colorado



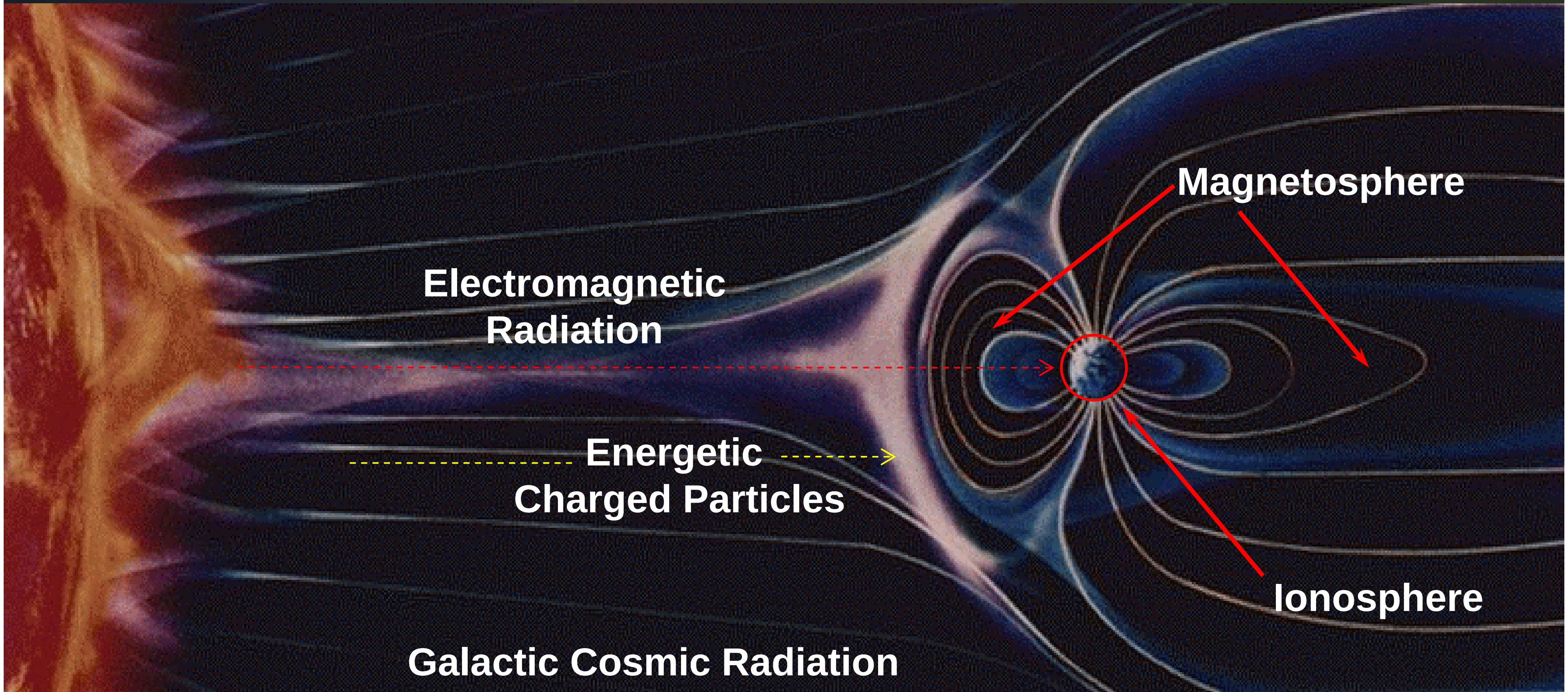
International Air Safety & Climate Change Conference (IASCC)
Cologne, 8-9 Sep, 2010

Outline

- What is space weather
- Customer growth/awareness
- The Solar Cycle
- Space Weather types and Impacts
    - Solar Flares (R Scale)
    - Radiation Storms (S Scale)
    - Geomagnetic Storms (G Scale)
    - International activities



Space Weather and the Space Environment

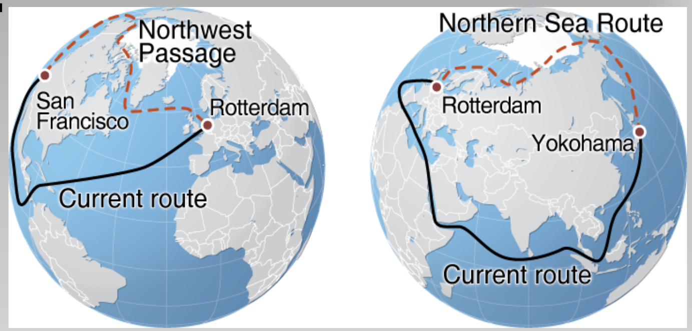


- **Solar electromagnetic radiation and energetic particles impact Earth's Magnetosphere and Ionosphere, causing space weather disturbances.**

Drivers for Space Weather Services

Growing demands for space weather products are being driven by the increasingly complex evolution of our global technological infrastructure

- **Evolving technologies:**
  - *Civil precision Global Navigation Satellite Systems*
  - *Power grids*
  - *Satellites (private and government)*
- **Evolving customers and industries:**
  - *Commercial space enterprise*
  - *Arctic economic development*
  - *Airspace management needs*
  - *Global partnerships and opportunities*



Modernization of International Airspace System

Next Generation Air Transportation System (NextGen) - FAA plan to modernize the National Airspace System through 2025.

SESAR (Single European Sky ATM Research) - European air traffic control infrastructure modernization program

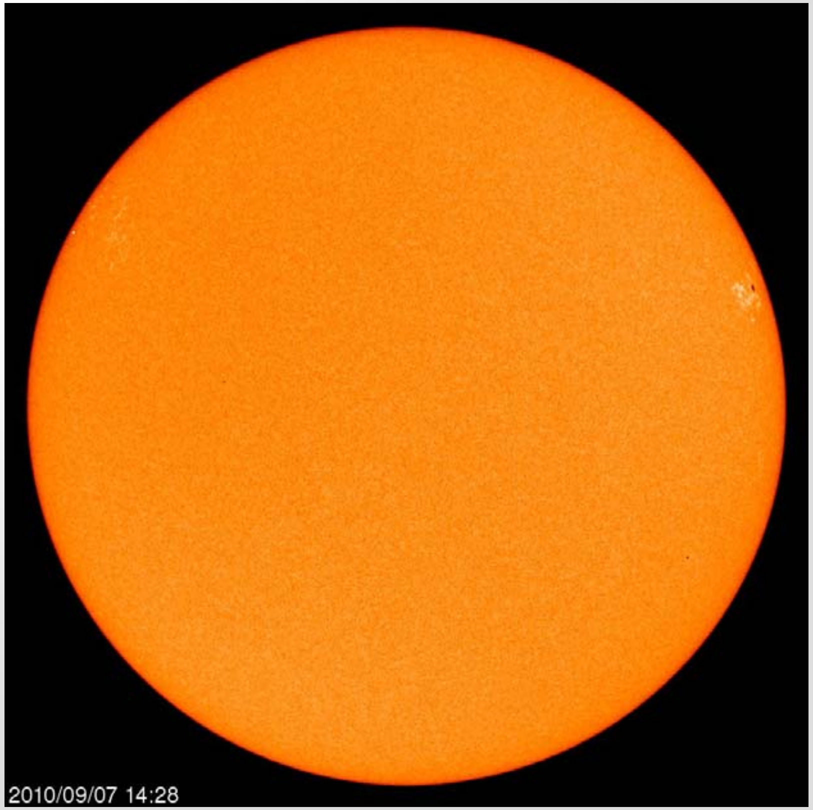
- SWPC currently working closely with NextGen team on space weather requirements

- International colaboration on space weather services is vital

Sunspots and the Solar Cycle

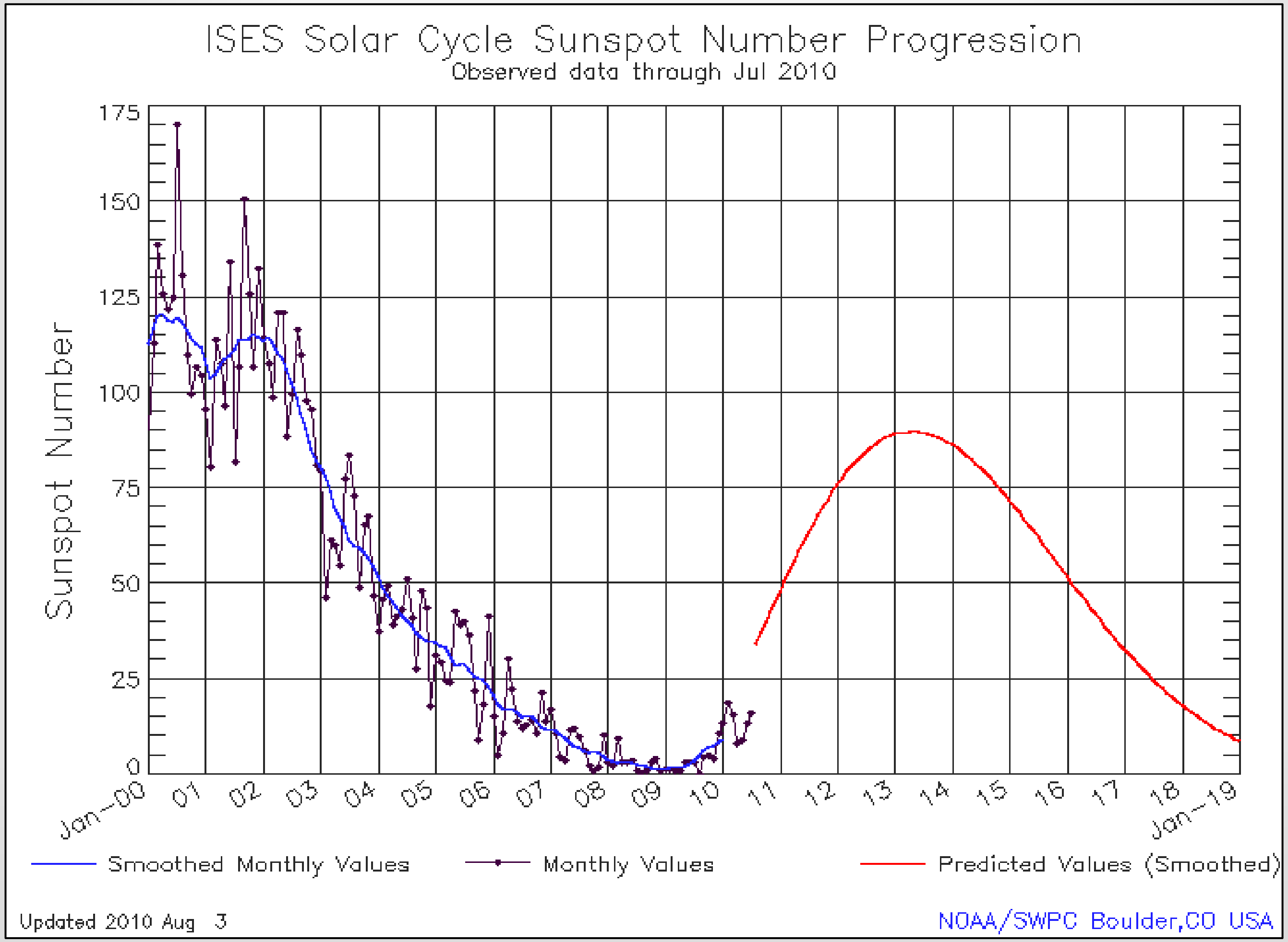
The Sun at solar maximum

~27 day full rotation



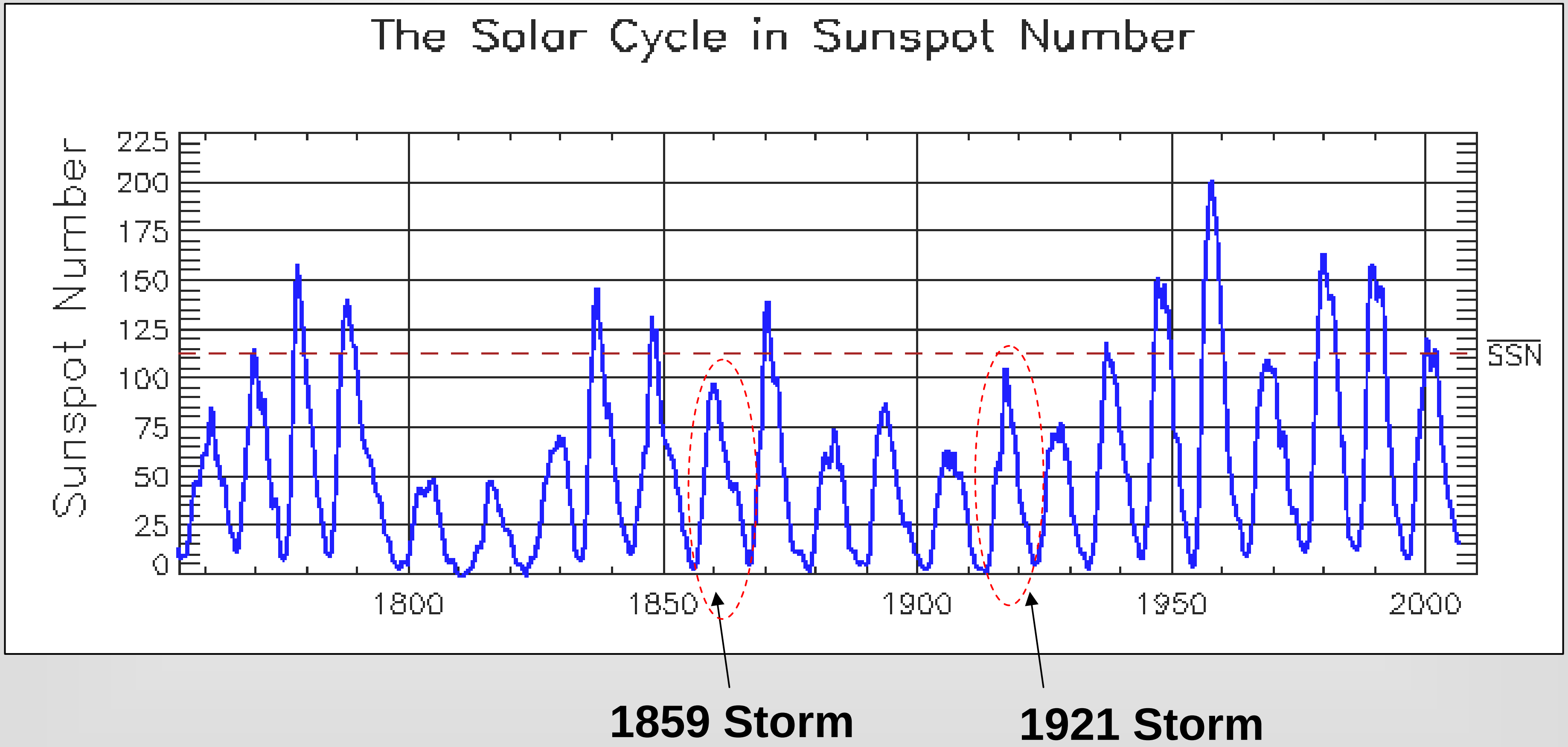
Status of Solar Cycle – Smoothed Sunspot Number (SSN)

- Cycle 23 began in May 1996
- Peak in April 2000 with SSN = 120
- Solar minimum in December 2008
- Solar Cycle 24 underway



• Large geomagnetic storms can occur with smaller cycles

• The largest geomagnetic storms on record occurred during lower than average cycles



NOAA Space Weather Scales

http://www.swpc.noaa.gov/NOAAscales/

Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
		Radio Blackouts		
R 5	Extreme	**HF Radio:**Complete HF (high frequency**) radio blackout on t sunlit side of the Earth lasting for a number of hours. This result radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritim aviation systems experience outages on the sunlit side of the Ear hours, causing loss in positioning. Increased satellite navigation positioning for several hours on the sunlit side of Earth, which n into the night side.		
R 4	Severe	**HF Radio:** : HF radio communication blackout on most of the s Earth for one to two hours. HF radio contact lost during this tim **Navigation:** Outages of low-frequency navigation signals cause error in positioning for one to two hours. Minor disruptions of sa navigation possible on the sunlit side of Earth.		
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, los contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for abo		
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sun of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals fo minutes.		
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communica side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for bri		

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but considered.
** Other frequencies may also be affected by these conditions.

Radio Blackouts

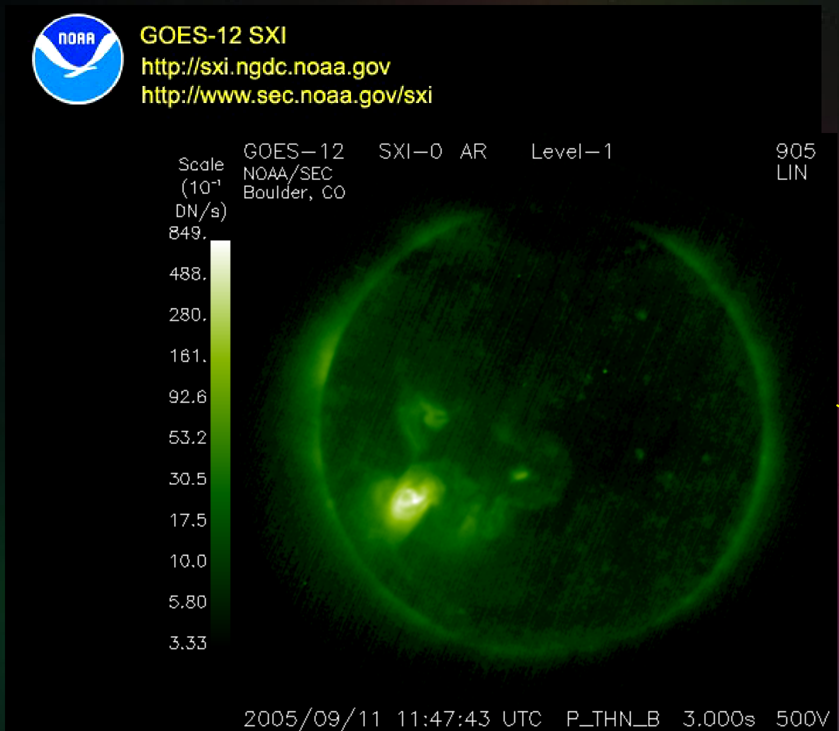
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects	Flux level	Number of
		Solar Radiation Storms		
S 5	Extreme	**Biological:** unavoidable high radiation hazard to astronauts on E vehicular activity); high radiation exposure to passengers and cre commercial jets at high latitudes (approximately 100 chest x-rays **Satellite operations:** satellites may be rendered useless, memory cause loss of control, may cause serious noise in image data, star be unable to locate sources; permanent damage to solar panels po **Other systems:** complete blackout of HF (high frequency) comm possible through the polar regions, and position errors make navi operations extremely difficult.		
S 4	Severe	**Biological:** unavoidable radiation hazard to astronauts on EVA; radiation exposure to passengers and crew in commercial jets at h (approximately 10 chest x-rays) is possible. **Satellite operations:** may experience memory device problems a imaging systems; star-tracker problems may cause orientation pro solar panel efficiency can be degraded. **Other systems:** blackout of HF radio communications through th regions and increased navigation errors over several days are like		
S 3	Strong	**Biological:** radiation hazard avoidance recommended for astrona passengers and crew in commercial jets at high latitudes may rec radiation exposure (approximately 1 chest x-ray). **Satellite operations:** single-event upsets, noise in imaging syste reduction of efficiency in solar panel are likely. **Other systems:** degraded HF radio propagation through the pola navigation position errors likely.		
S 2	Moderate	**Biological:** none. **Satellite operations:** infrequent single-event upsets possible. **Other systems:** small effects on HF propagation through the pol navigation at polar cap locations possibly affected.		
S 1	Minor	**Biological:** none. **Satellite operations:** none. **Other systems:** minor impacts on HF radio in the polar regions.		

Radiation Storms

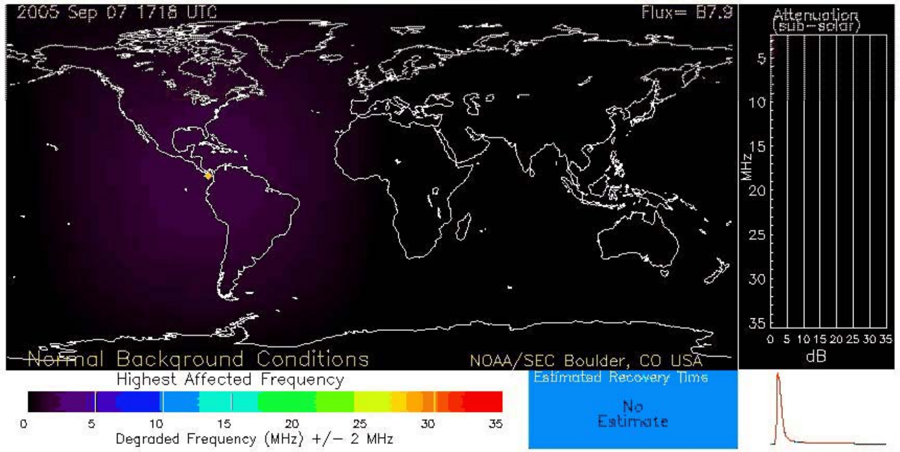
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
		Geomagnetic Storms	Kp values* determined every 3 hours	Number of storm events when Kp level was met
G 5	Extreme	**Power systems:** : widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp = 9	4 per cycle (4 days per cycle)
G 4	Severe	**Power systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp = 7	200 per cycle (130 days per cycle)
G 2	Moderate	**Power systems:** high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp = 6	600 per cycle (360 days per cycle)
G 1	Minor	**Power systems:** weak power grid fluctuations can occur. **Spacecraft operations:** minor impact on satellite operations possible. **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp = 5	1700 per cycle (900 days per cycle)

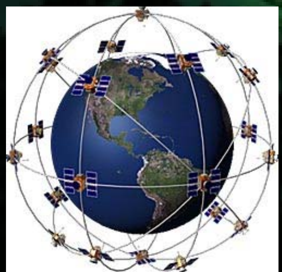
Geomagnetic Storms

Solar Flares

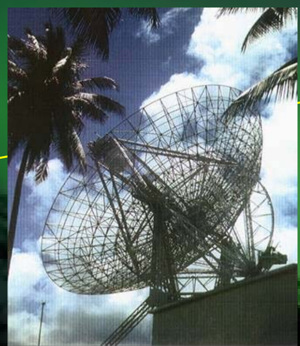


- *A violent* explosion in the Sun's atmosphere with an energy equivalent of a hundred million hydrogen bombs.





GPS Network



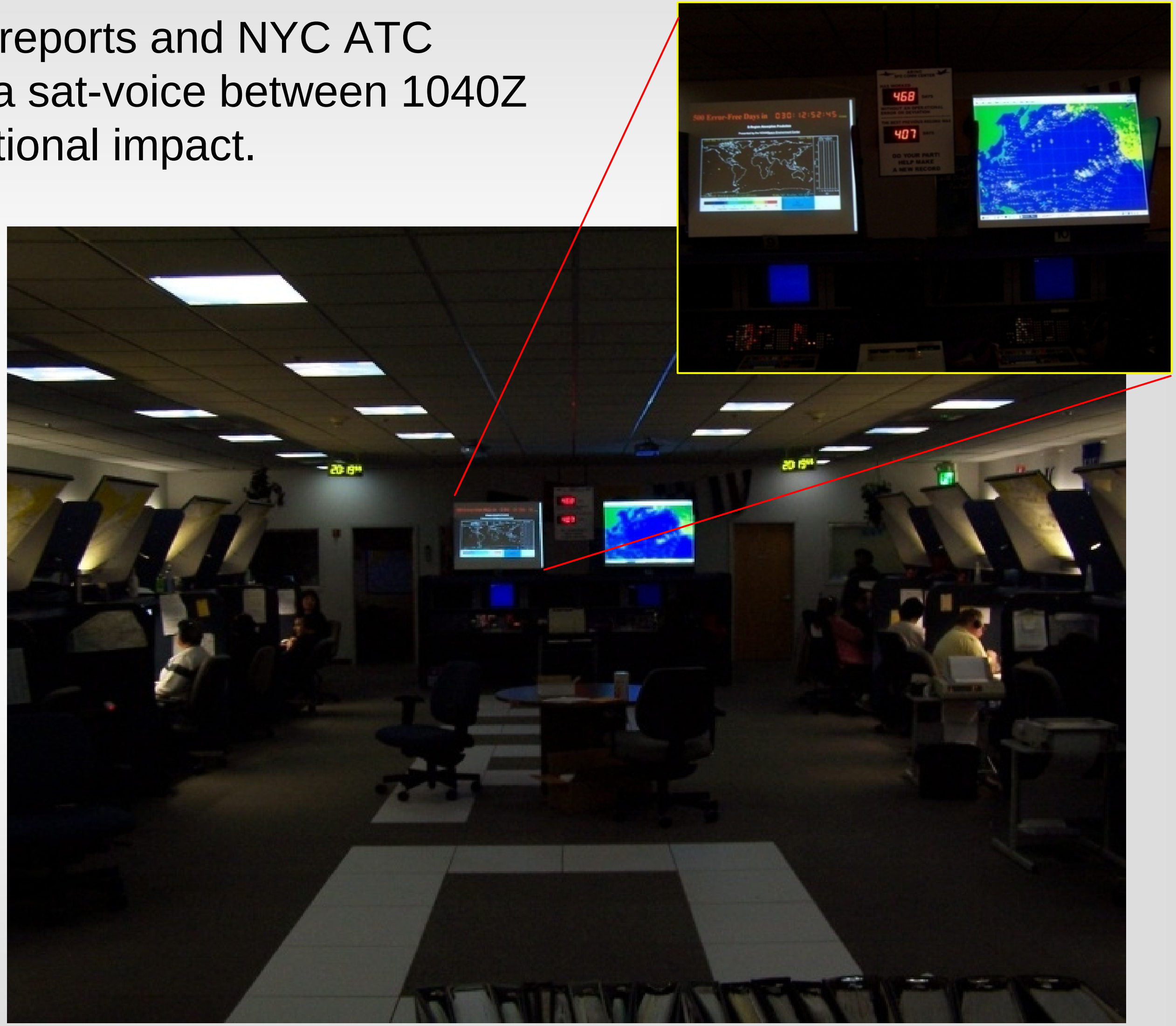
Ground and Space-based Communications

Radar

Aircraft Operations

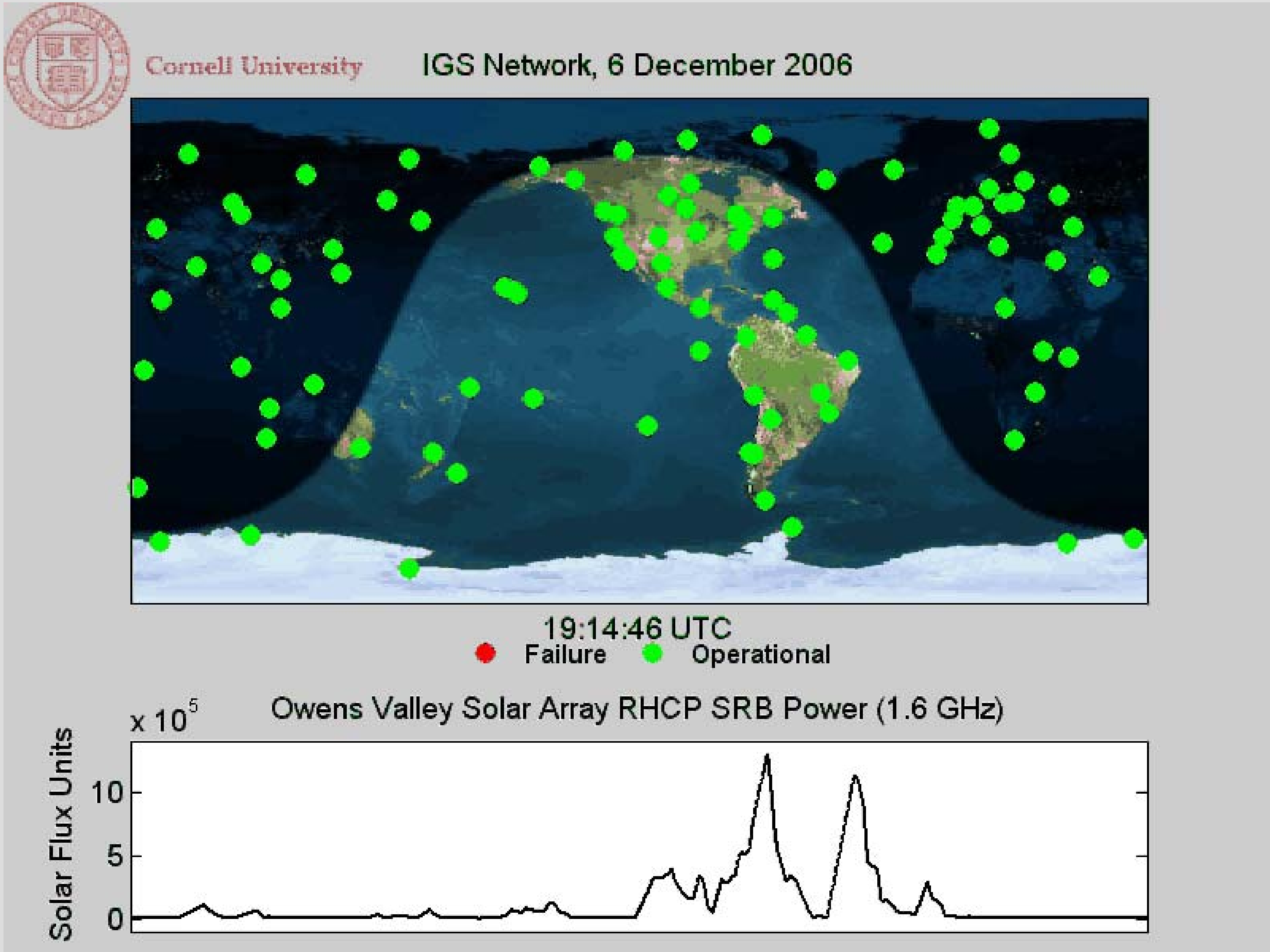
Communication Center:
07Sep05 1800Z: Solar activity severely impacted all HF comms. Higher frequencies utilized with little effect. 24 aircraft position reports and NYC ATC messages were relayed via sat-voice between 1040Z and 1939Z.. Severe operational impact.

“The flare resulted in significant impacts to the network of air traffic control radars in Canada, causing false targets and interference in the N/S direction on scales of approximately 150 miles in length.”

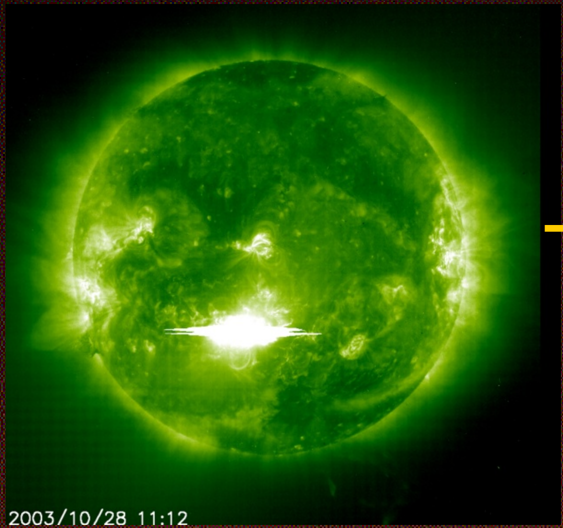


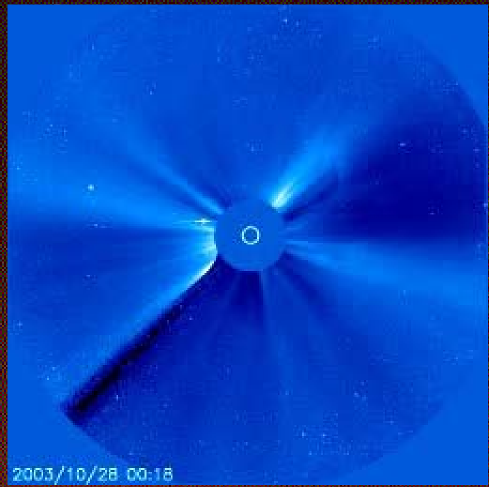
D-region HF Communications plot at ARINC Center at SFO

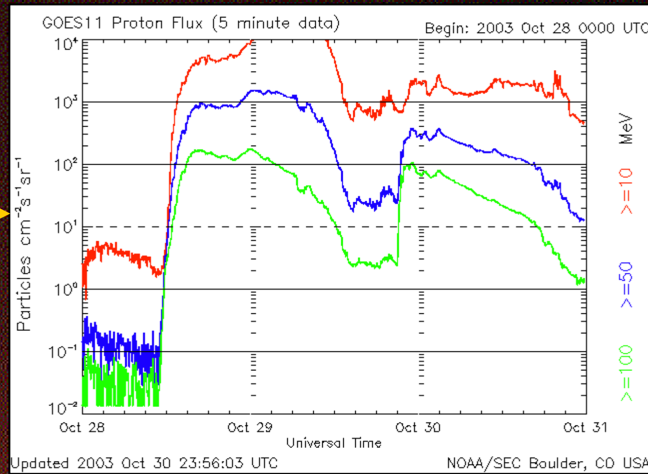
Solar Flare Impact on GPS

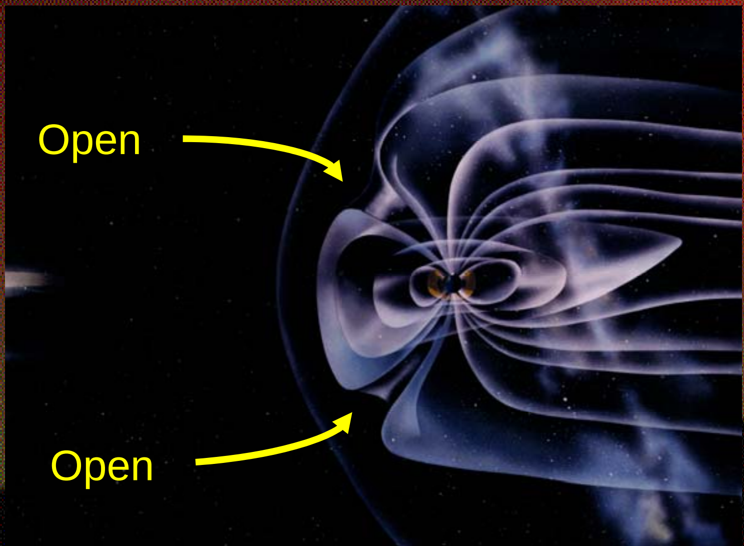


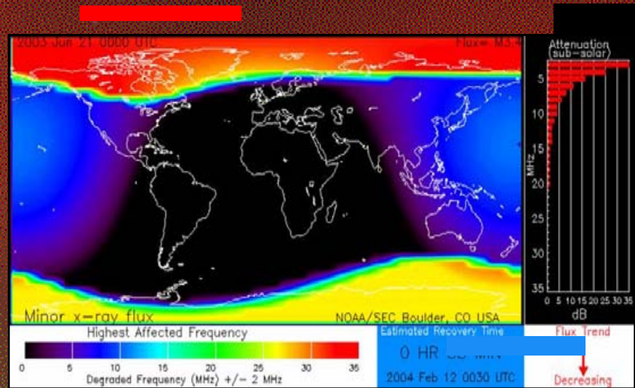
Solar Radiation Storms

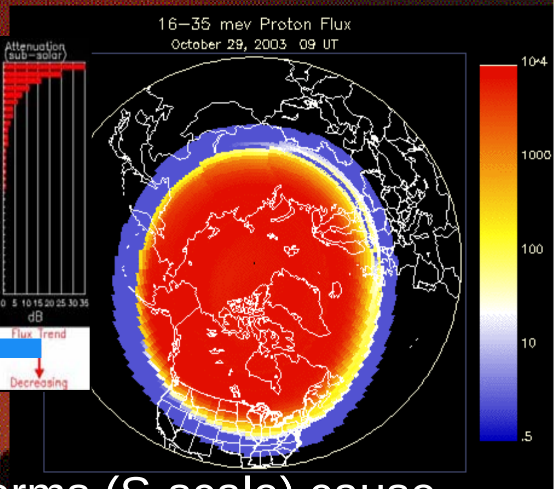












Solar Radiation Storms (S-scale) cause extended periods (hours to days) of HF comm blackouts at **higher** latitudes.

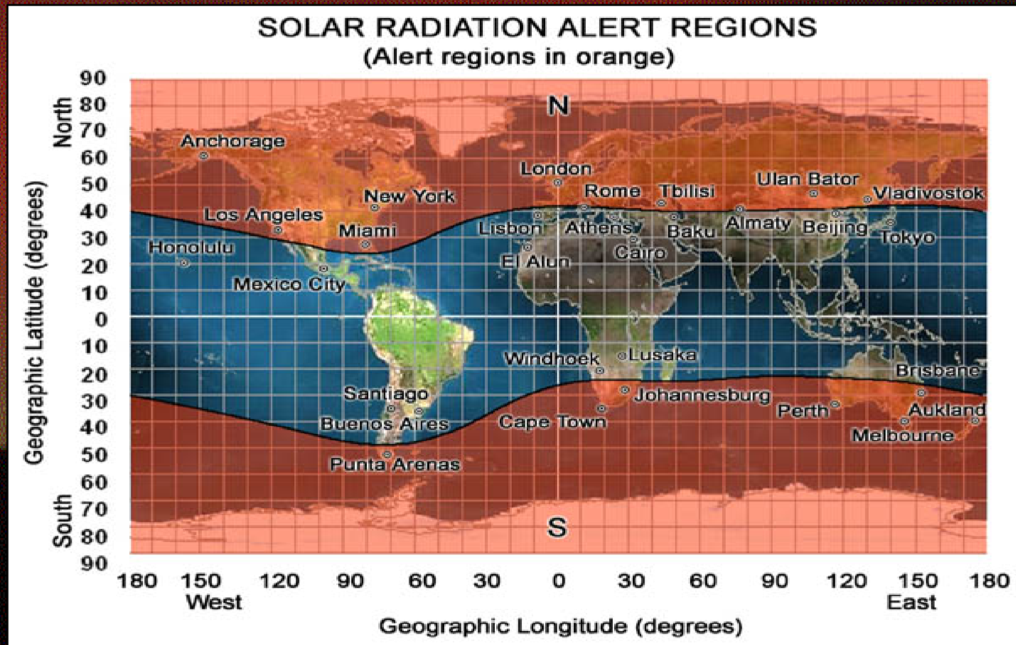
Airlines avoid polar routes during Radiation Storms due to both exposure and communications concerns

Low latitude concerns also exist:

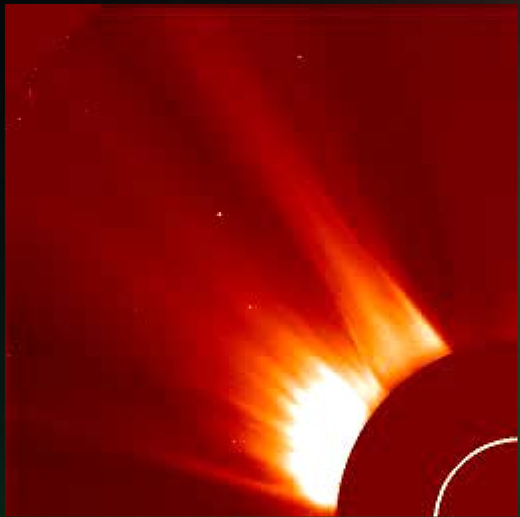
ALERT*: Solar Radiation Alert at Flight Altitudes Conditions Began: 2003 Oct 28 2113 UTC*

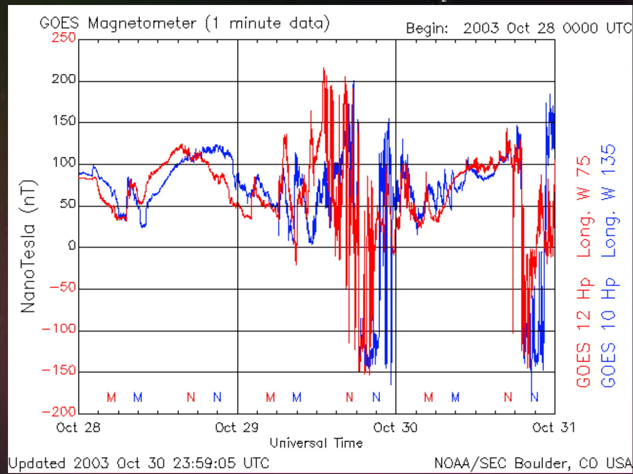
Comment: ***Satellite measurements indicate unusually high levels of ionizing radiation, coming from the sun. This may lead to excessive radiation doses to air travelers at Corrected Geomagnetic Latitudes above 35 degrees north, or south.***

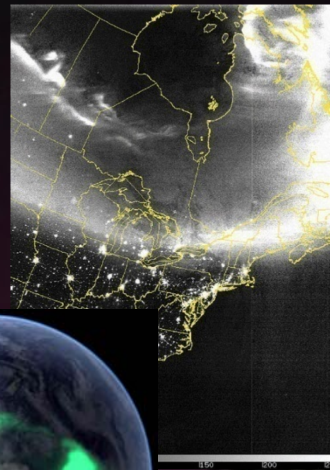
(Federal Aviation Administration)

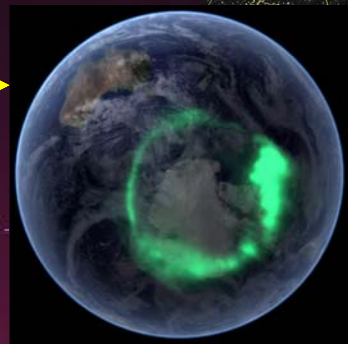


Geomagnetic Storms

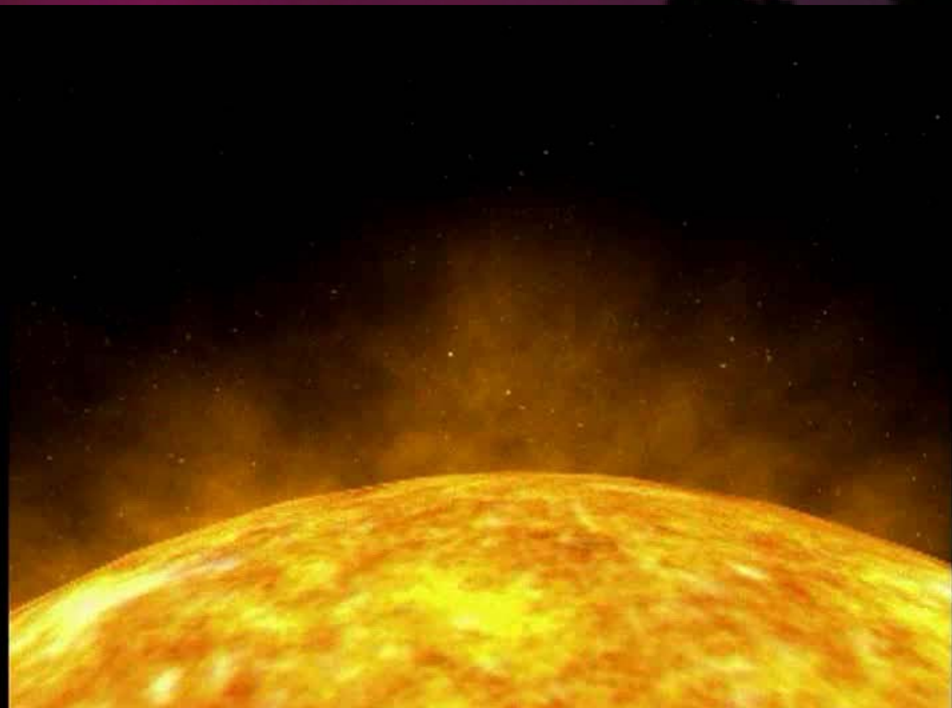








- Coronal Mass Ejections (CME) propagate through space at 2-3 million mph
- Impact Earth in 20 - 90 hours
- Geomagnetic Storm begins when CME impacts Earth



Geomagnetic storms also impact communications – primarily HF comm in high and polar latitudes.

CZEG EDMONTON CENTRE (ACC)

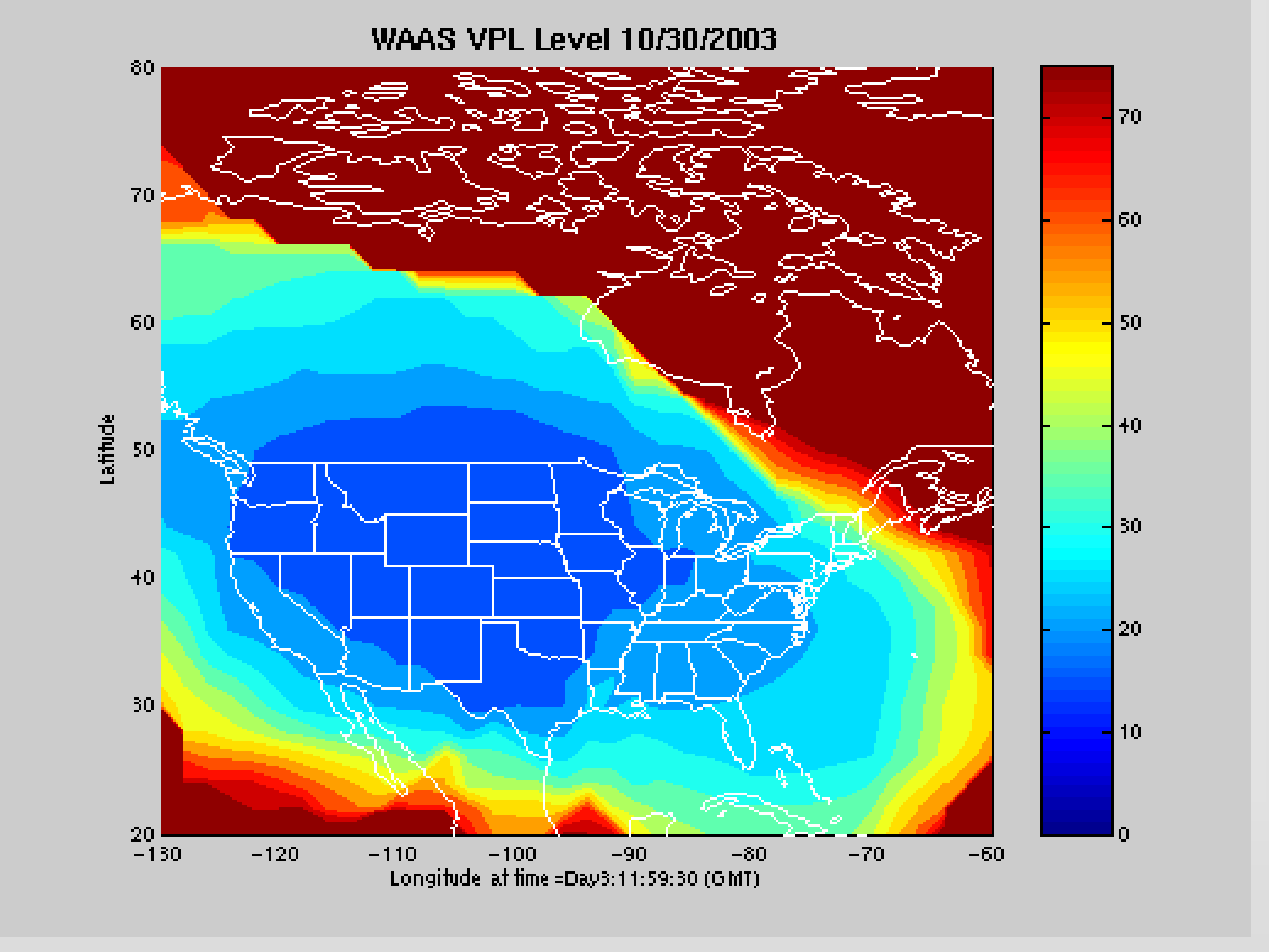
A8577/03 - <u>ROUTE AND LEVEL RESTRICTIONS DUE TO GEO-MAGNETIC STORM</u>

IMPACT ON COMM IN EDMONTON ACC ALL FLT TRANSITING CZEG FIR N OF 5700N AT FL290 OR ABOVE: 1. NORTHBOUND POLAR FLT PROCEEDING OVER DEVID, ORVIT

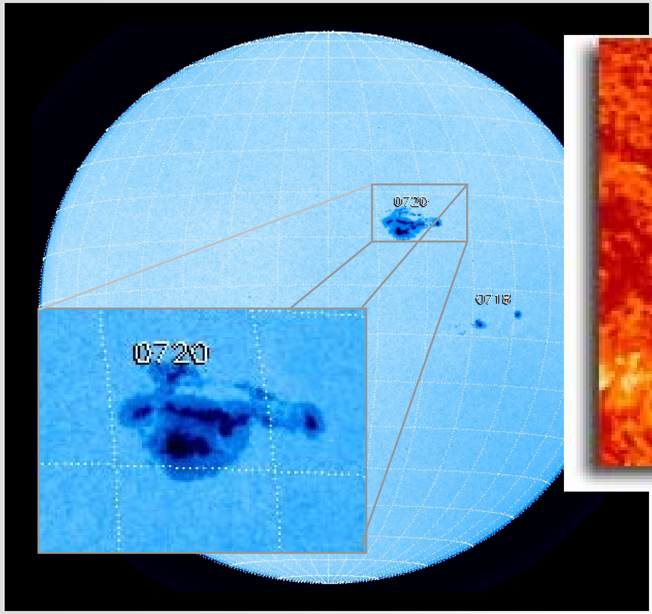
<u>… ARE ADVISED THAT VHF AND HF COMM RELAYED FROM THE TRANS SITE TO ATC VIA SATELLITE MAY FAIL DUE TO THE EFFECTS OF THE CURRENT INTENSE MAGNETIC STORM</u>.

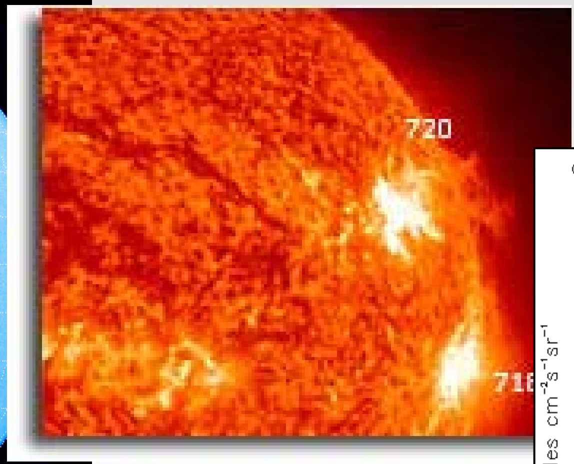
Geomagnetic Storm impact on GPS

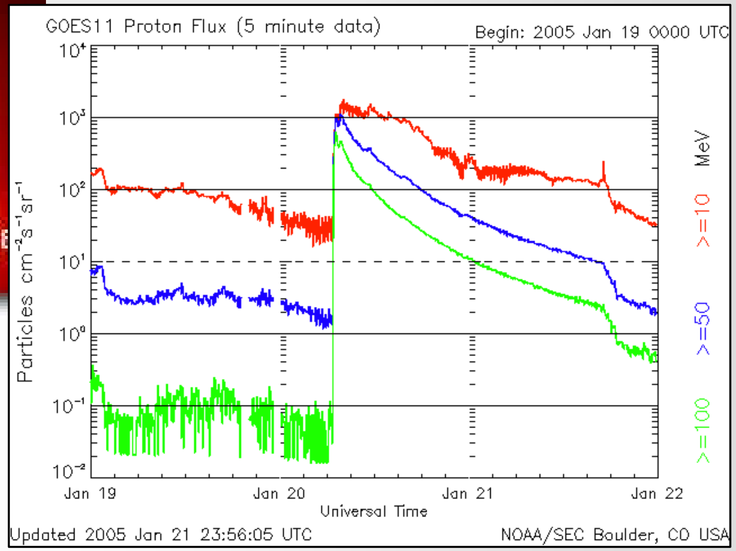
For 15 and 11-hour periods in Oct 2003, the ionosphere was so disturbed that the vertical error limit, as defined by the FAA to be no more that 50 meters, was exceeded.



Impact on Airlines – January 2005







<u>JANUARY 2005 – United Airlines</u>

- **26 FLIGHTS OPERATED ON LESS THAN OPTIMUM POLAR ROUTES DUE TO SOLAR ACTIVITY**
- ***CHICAGO TO HONG KONG*** ANCHORAGE STOP 4 CONSECUTIVE DAYS, PENALTY 180 TO 210 MINUTES
- ***CHICAGO TO BEIJING*** PENALTIES 18 TO 55 MINUTES
- ***BEIJING TO CHICAGO*** PENALTIES 55 MINUTES TO 80 MINUTES

Space Weather in the International Civil Aviation Organization (ICAO)

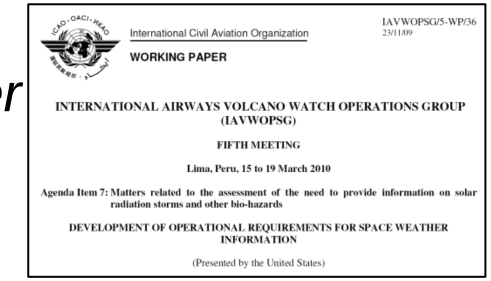
- International Civil Aviation Organization Divisional Meeting (2002)
  - Space weather recognized as a hazard to aviation.

- Two significant operational issues in international air navigation require the ICAO to address space weather:
  - Significant increase in polar operations
  - Increased use of GNSS for navigation

- These issues were brought to the ICAO Air Navigation Commission (ANC). ANC suggested that space weather be addressed by the International Airways Volcano Watch Operations Group (IAVWOPSG).

Space Weather in the International Civil Aviation Organization

- At the 5th meeting of the IAVWOPSG in Peru, *March 2010,* the U.S. presented the "*Manual on Space Weather Effects in Regard to International Air Navigation*"



IAVWOPSG/5-WP/36
23/11/09

International Civil Aviation Organization

WORKING PAPER

INTERNATIONAL AIRWAYS VOLCANO WATCH OPERATIONS GROUP (IAVWOPSG)

FIFTH MEETING

Lima, Peru, 15 to 19 March 2010

Agenda Item 7: Matters related to the assessment of the need to provide information on solar radiation storms and other bio-hazards

DEVELOPMENT OF OPERATIONAL REQUIREMENTS FOR SPACE WEATHER INFORMATION

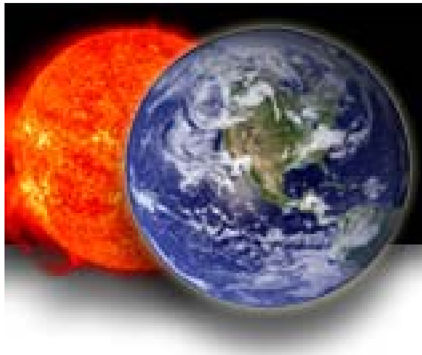
(Presented by the United States)

- Working Paper presented on the *"Development of Operational Requirements for Space Weather Information"*

Group formed to address space weather requirements that includes: Argentina, Australia, Canada, France, New Zealand, United Kingdom, United States (Rapporteur), IATA, IFALPA and IFATCA, in consultation with ICAO and WMO.

- Develop draft operational requirements for space weather, including draft guidance material (on use of products), as necessary.

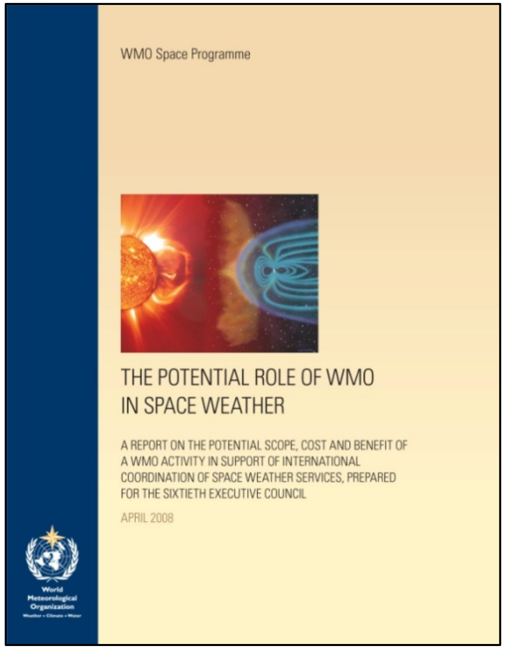
- Prepare a report with milestones for the development and roll-out of space weather service for international aviation, for consideration by the IAVWOPSG/6.



Space Weather in the World Meteorological Organization

WMO – “UN system's authoritative voice on the state and behavior of the Earth's atmosphere”…*extends now to the space environment!*

June 08: Executive Council (EC-LX) endorsed principle of WMO activities in support of space weather.



WMO Space Programme

THE POTENTIAL ROLE OF WMO IN SPACE WEATHER

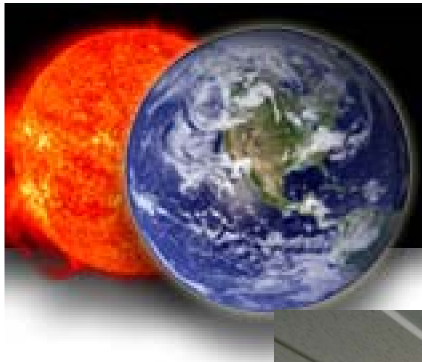
A REPORT ON THE POTENTIAL SCOPE, COST AND BENEFIT OF A WMO ACTIVITY IN SUPPORT OF INTERNATIONAL COORDINATION OF SPACE WEATHER SERVICES, PREPARED FOR THE SIXTIETH EXECUTIVE COUNCIL

APRIL 2008

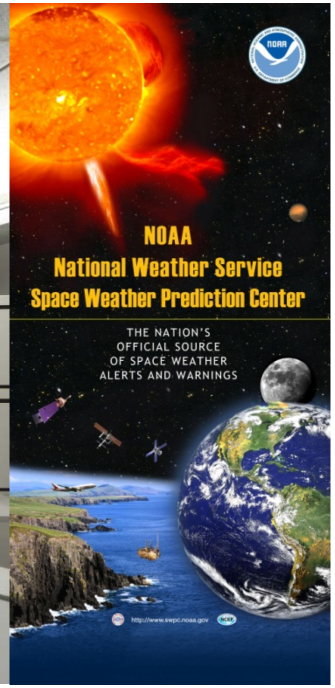
World Meteorological Organization

April 09: WMO Commission on Basic Systems (CBS) agreed to Terms of Reference of Inter-program Coordination Team on Space Weather (ICTSW) with CBS-CAeM (Commission for Aeronautical Meteorology) co-leadership.

Sept 09: Circular letter to 188 WMO members, ICAO, IMO, ITU, ESA, COPUOS informed on ICTSW, proposed participation, invited POC



NOAA Space Weather Prediction Center



SWPC: www.spaceweather.gov

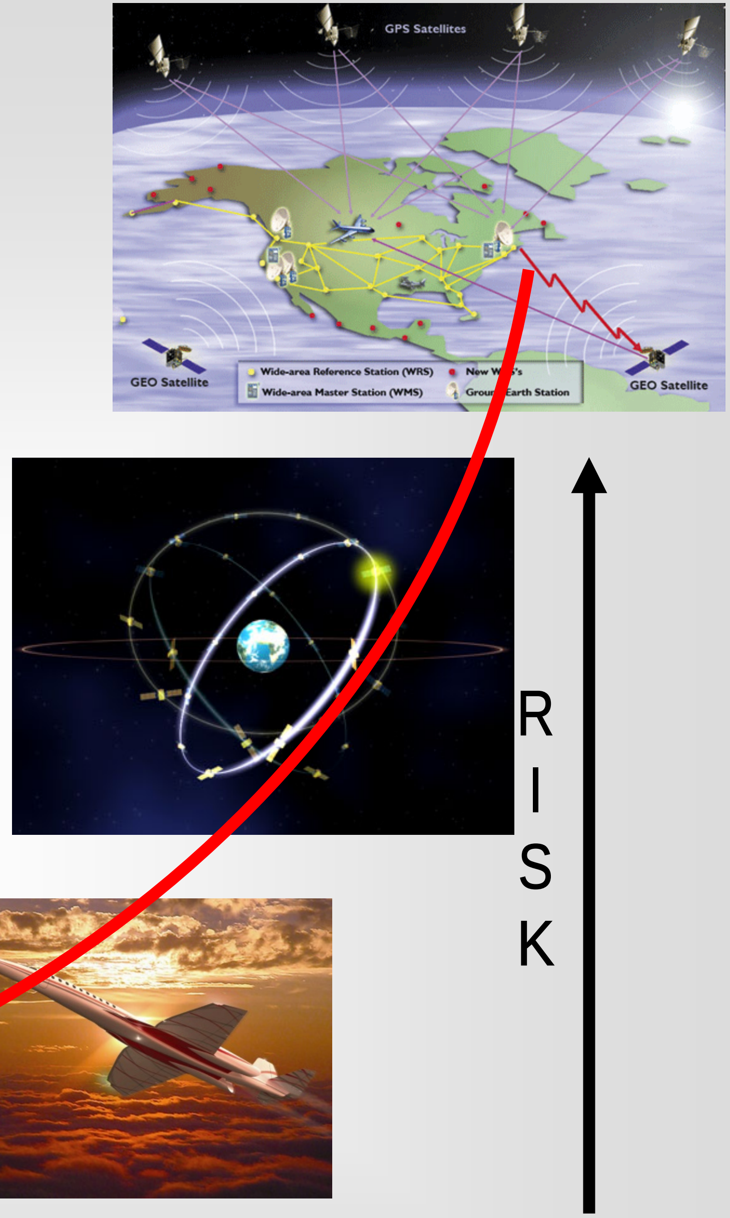
SWPC Alerts/Warnings: www.swpc.noaa.gov/alerts/index.html
(includes link to Product Subscription Service)

SWPC Data and Products: www.swpc.noaa.gov/Data/index.html

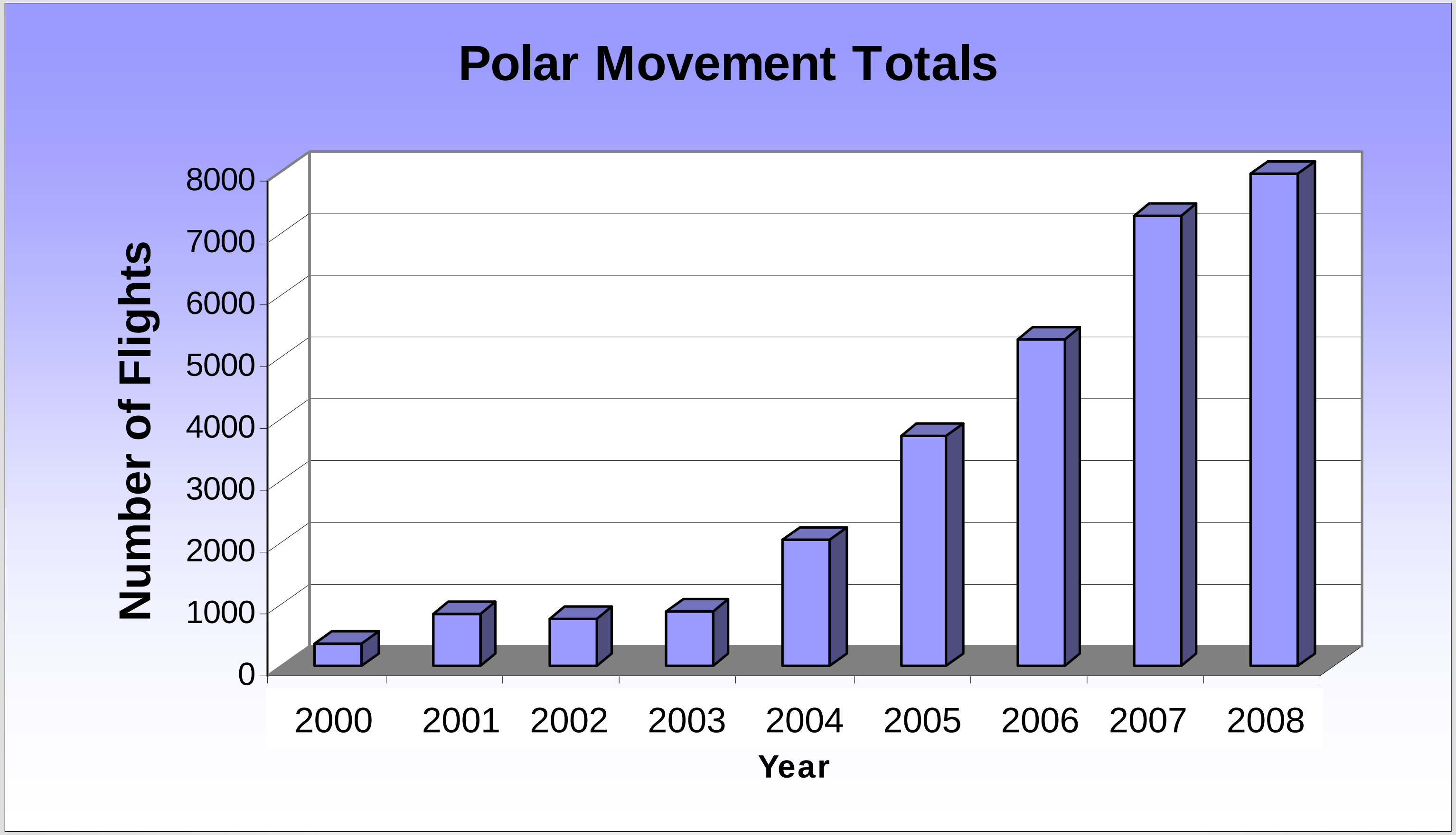
•Space weather storms have global impacts, and the UN now recognizes the increasing need to monitor and manage this risk.

•The UN wants to include space weather in key UN agencies to facilitate cooperation in global economic development, and social progress.

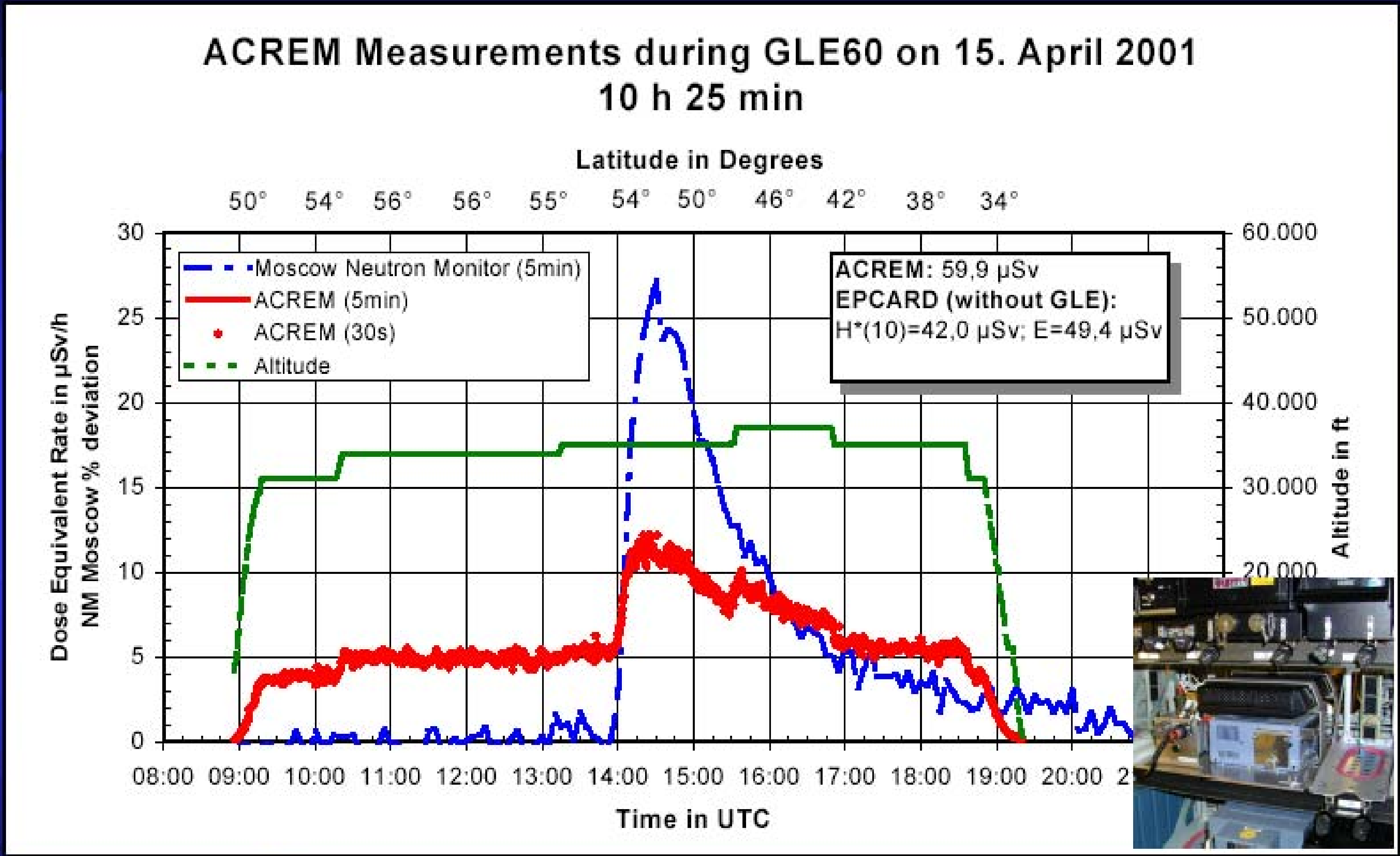
• Opportunity for ISES to play key role in global efforts to meet space weather needs of rapidly evolving aviation industry



Cross Polar Aviation



Polar Route Passenger Movement				
	2004	**2009**	**2014**	**2019**
Capacity	**228,000**	**384,000**	**972,000**	**1,768,000**
Avg. Annual Growth Rate		**13.9%**	**20.4%**	**12.7%**


ACREM Measurements during GLE60 on 15. April 2001
10 h 25 min
Latitude in Degrees
50° 54° 56° 56° 55° 54° 50° 46° 42° 38° 34°
Moscow Neutron Monitor (5min)
ACREM (5min)
ACREM (30s)
Altitude
ACREM: 59,9 µSv
EPCARD (without GLE):
H*(10)=42,0 µSv; E=49,4 µSv
Dose Equivalent Rate in µSv/h
NM Moscow % deviation
Altitude in ft
0 5 10 15 20 25 30
60.000 50.000 40.000 30.000 20.000
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
Time in UTC

Warnings and Alerts to support airline space weather products

ENSCO, Inc.

SIGNIFICANT SOLAR WEATHER REPORT

KAL		*Issued By:*	Heidel
SOLAR ACTIVITY		*Date:*	19-20 Sep 2007
		Valid Time:	18z-06z

STATUS :

ADVISORY	**Radio Effects :**	**NONE**
	Solar Radiation :	**NONE**
	Navigation Effects :	**NONE**

Use the following scale to determine the effects from Solar Activity.

(R 1) Minor Impact on HF	(S 1) No Effects	(G 1) No Effects
(R 2) Small HF Effects	(S 2) No Effects	(G 2) Possible Errors
(R 3) Degraded HF	(S 3) Modify Flight Plan	(G 3) Positions Errors Likely
(R 4) HF Blackouts	(S 4) No Polar Flying	(G 4) Increased Errors
(R 5) Complete HF Blackout	(S 5) No Polar Flying	(G 5) Major Positions Errors

*****Note: For R2, R3, R4, or R5, consider POLAR 4 for routing purposes*****

SPACE WEATHER COMMENTS:

* Please see the Space Environment Center website: http://www.sec.noaa.gov/aviation/index.html

OTHER SIGNIFICANT WEATHER ROUTE ISSUES:

G 5	Extreme	**Power systems:** : widespread volta[...] system problems can occur, some [...] collapse or blackouts. Transformer[...] **Spacecraft operations:** may exper[...] problems with orientation, uplink/[...] **Other systems:** pipeline currents [...] frequency) radio propagation may [...] two days, satellite navigation may [...] radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.		
G 4	Severe	**Power systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora	Kp = 7	200 per cycle (130 days per cycle)

FAA publication *"**Galactic Cosmic Radiation Exposure of Pregnant Aircrew Members II**"*

"…80+ hours flying time per month on a high latitude would result in exposure of .57 millisieverts per month which would exceed the .5 millisieverts ICRP monthly recommendation for a pregnant person, and in two months would exceed the total limit for the term of the pregnancy i.e. 1 millisievert."

"The situation is unchanged. Galactic cosmic radiation on high-altitude, high-latitude flights can accumulate to exceed the 500 mSv monthly dose limit recommended by the NCRP."

Wallace Friedberg, Ph.D.
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

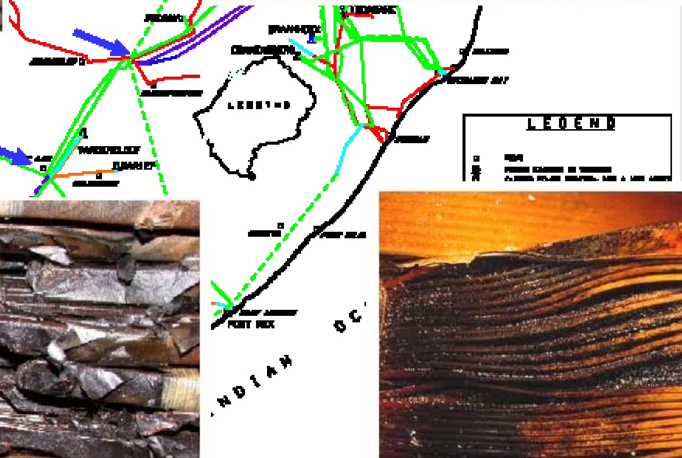
- *For a pregnant crewmember, the recommended limit for the fetus is an equivalent dose of 1 mSv, with no more than 0.5 mSv in any month. The legal dose limit for the public (airline passengers) is 1 mSv per year.*

- It would be extremely rare for any single Solar Energetic Proton (SEP) event to produce dose rates exceeding the occupational exposure limits of 20 mSv per year. However, there are approximately 3-5 SEP events over the 11-year solar cycle, where exposure issues become a concern for passengers and pregnant crew members.

ESKOM (South Africa) Network reports - 5 Stations, ± 15 Transformers damaged

Station 4 Transformer 6 HV winding failure

Station 3 Transformer 6 LV exit lead overheating



Station 5 Transformer 2

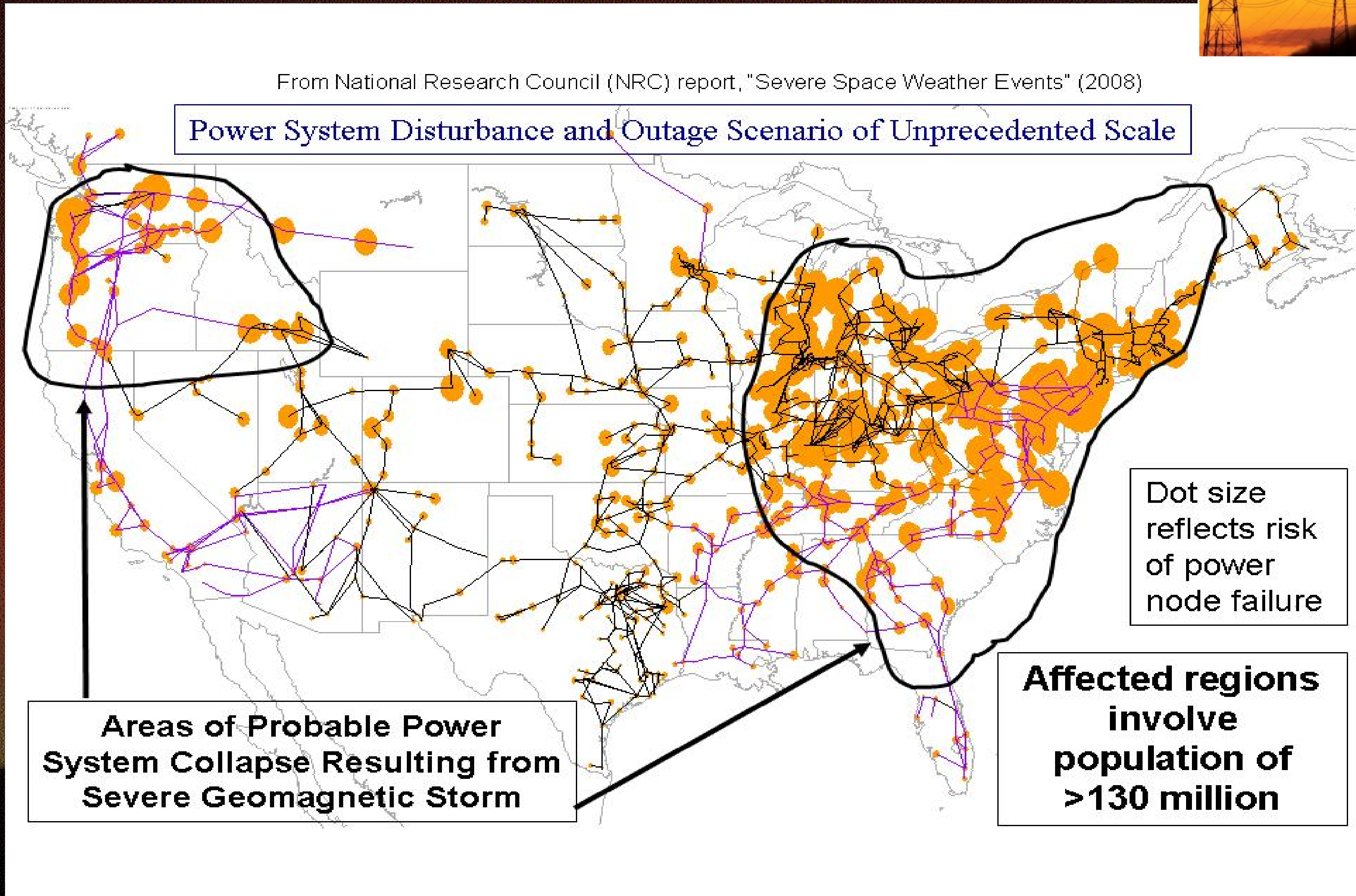
Station 3 Gen Transformer 4 damage

Station 3 Gen. Transformer 5 overheating

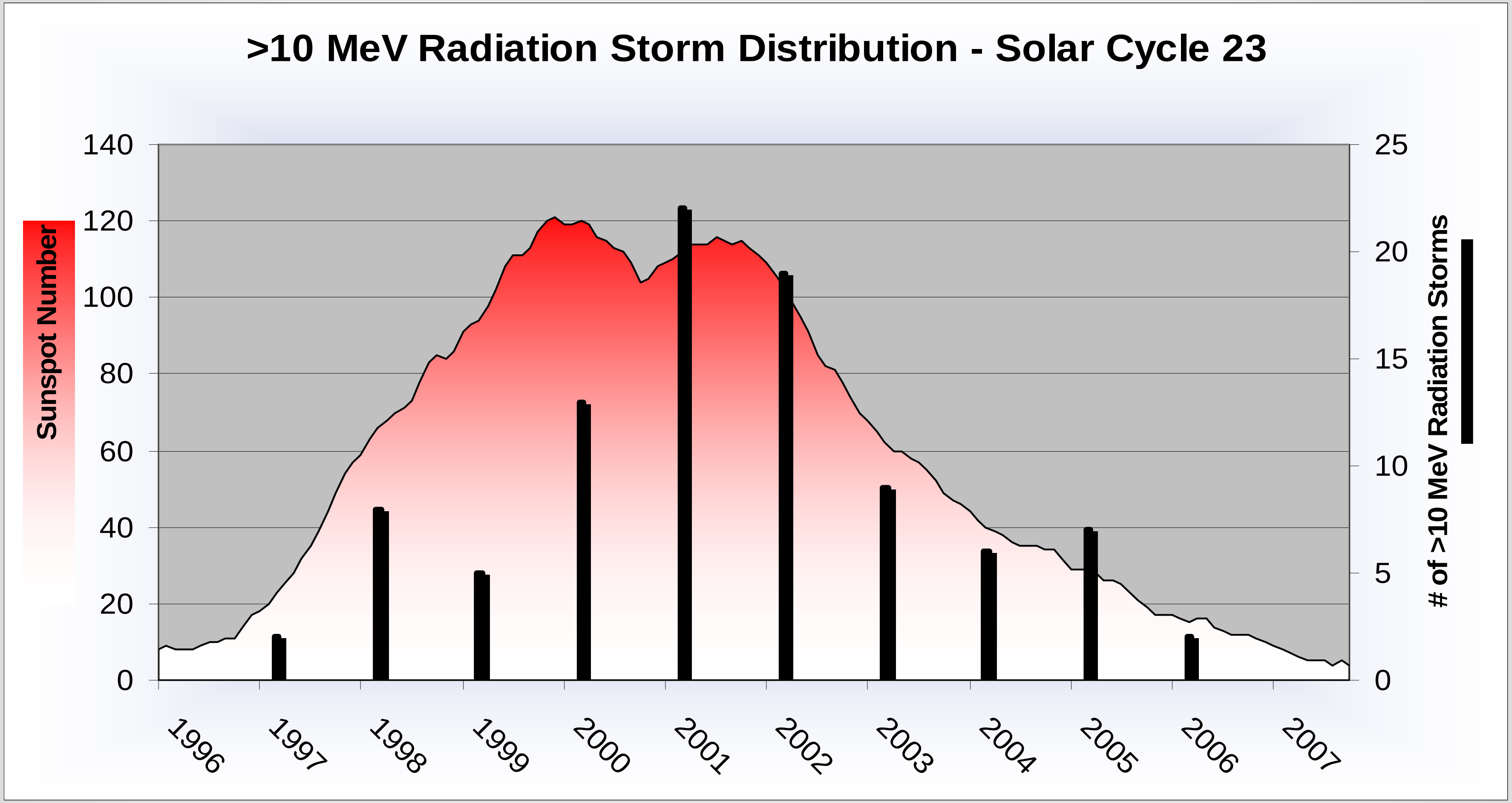
Worst Case…

$1-2 Trillion – Cost of blackout

4-10 years - Recovery time

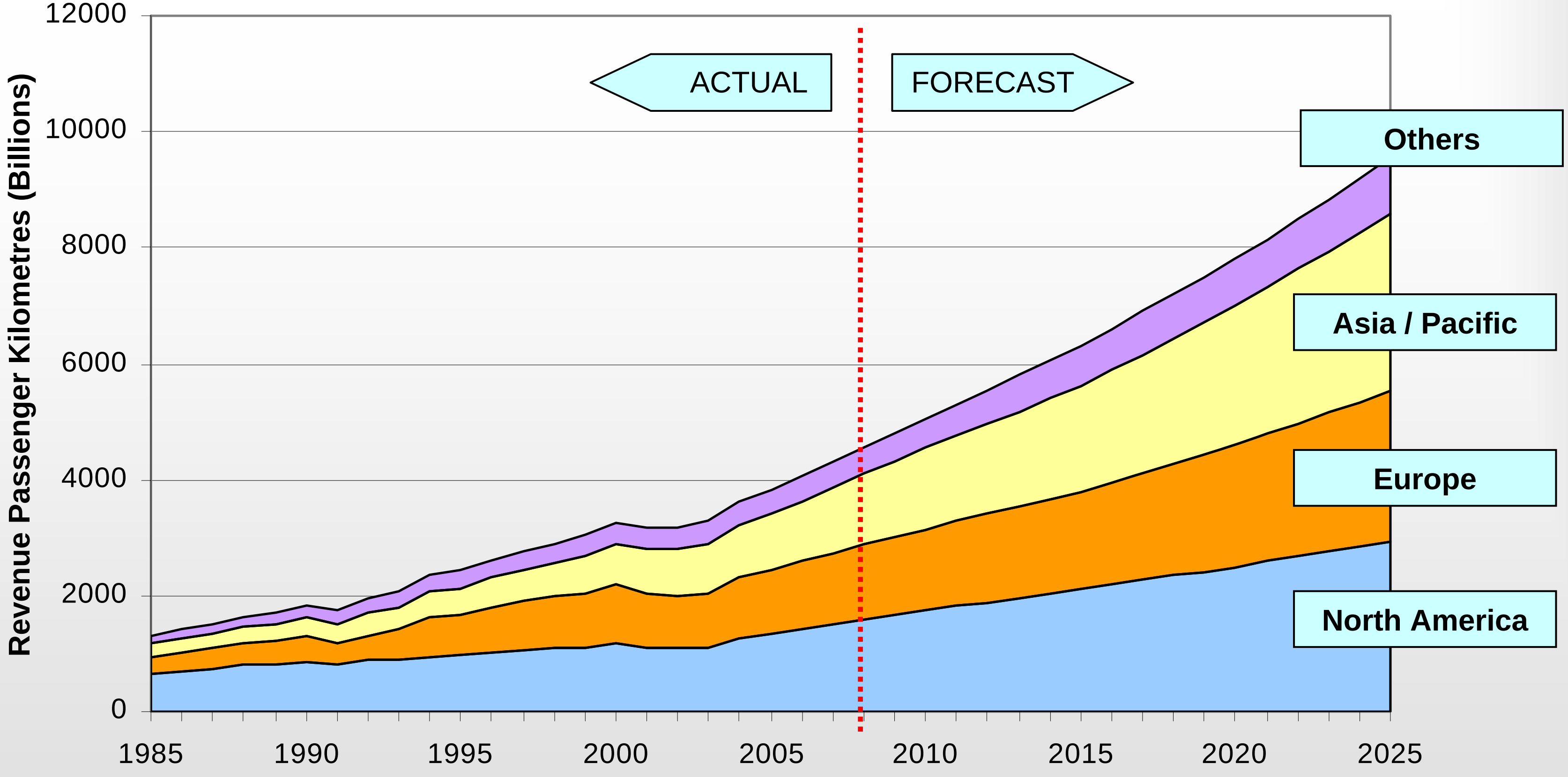


Solar Radiation Storms (NOAA S-scale)



- Radiation storms are infrequent during the solar minimum years

GROWTH OF AIR TRAFFIC



Ref: Worldwide Market Forecast for Commercial Air Transport, JADC

Solar Flare Radio Blackouts (NOAA R-scale)

Category: Scale	Category: Descriptor	Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
		Duration of event will influence severity of effects		
		Radio Blackouts	**GOES X-ray peak brightness by class and by flux***	**Number of events when flux level was met**
R 5	**Extreme**	**HF Radio:**Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R 4	**Severe**	**HF Radio:** : HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	**Strong**	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	**Moderate**	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	**Minor**	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

Solar Radiation Storms (NOAA S-scale)

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

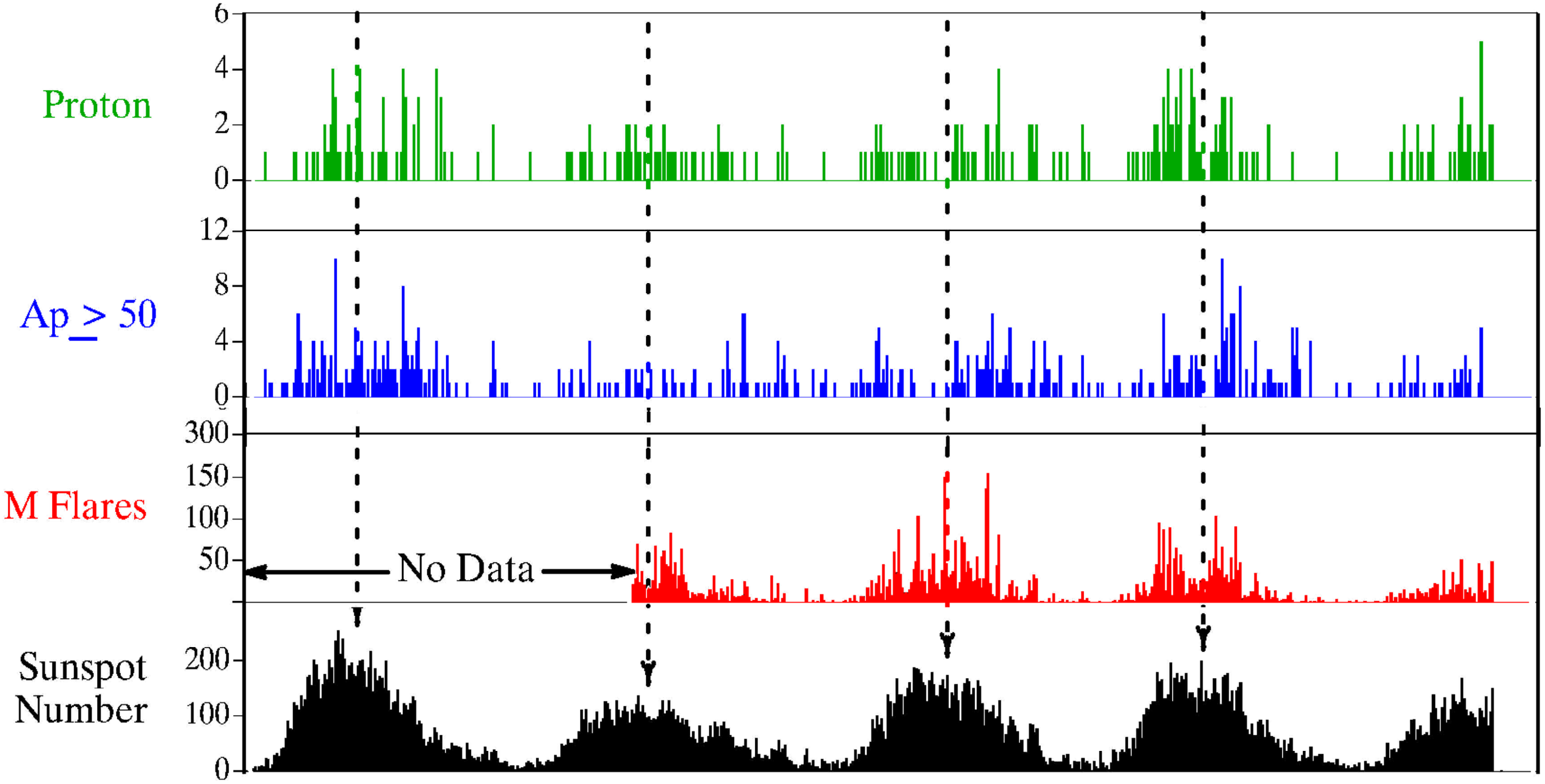
- The NOAA space weather radiation scale is based on ≥10 MeV protons measured on the GOES spacecraft

Geomagnetic Storms (NOAA G-scale)

G 5	**Extreme**	**Power systems:** : widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp = 9	4 per cycle (4 days per cycle)
G 4	**Severe**	**Power systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	**Strong**	**Power systems:** voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp = 7	200 per cycle (130 days per cycle)
G 2	**Moderate**	**Power systems:** high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp = 6	600 per cycle (360 days per cycle)
G 1	**Minor**	**Power systems:** weak power grid fluctuations can occur. **Spacecraft operations:** minor impact on satellite operations possible. **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp = 5	1700 per cycle (900 days per cycle)

- **“Eurocontrol Studying Effects Of Solar Events On GNSS Signals.”**
  Inside GNSS
- (7/1) , "Eurocontrol, Europe's air traffic control agency, is studying the effect of solar events on civil aviation applications and developing ways to maintain air safety when GNSS signals are affected." This is a "key" issue, according to the article, for the Single European Sky ATM Research (SESAR) program which will update Europe's air traffic control system. "Eurocontrol has contacted with French engineering consultants Egis Avia to study the effect of ionospheric disturbances on GNSS-based applications for different phases of flight, then develop and test mitigation techniques.”
  - *Inside GNSS*

http://mailview.custombriefings.com/mailview.aspx?m=2010070201aiaa&r=2913954-cede&l=020-9e7&t=c>



Proton
Ap > 50
M Flares
Sunspot Number
No Data
6
4
2
0
12
8
4
0
300
150
100
50
200
100
0

Directive 96/29/Euratom – Ionizing Radiation

- Establishes uniform basic safety standards to protect the health of workers and the general public against the dangers of ionising radiation.
- Article 42 of the Directive imposes requirements relating to the assessment and limitation of air crew members' exposure to cosmic radiation.