ICAO Space Weather Center Provisions

To: NAM/CAR/SAM Seminar on Space Weather

By: M. Pat Murphy, Federal Aviation Administration, U.S.

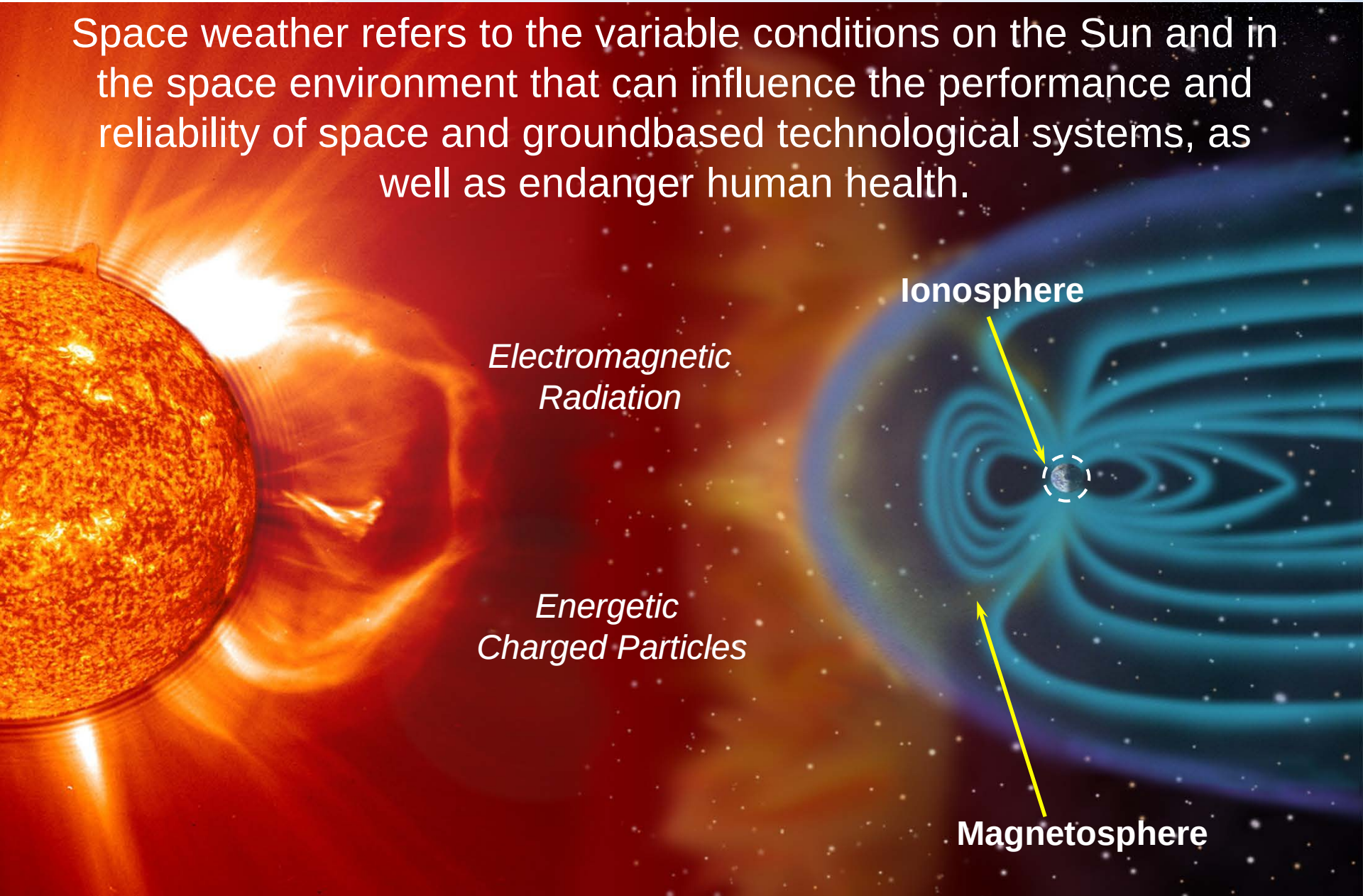
Date: July 16, 2018

Overview

- What is “Space Weather”
- Space Weather Phenomena
  - Solar Flares
  - Radiation Storms
  - Geomagnetic Storms
- Impacts to Aviation
- Services in ICAO

What is space weather?

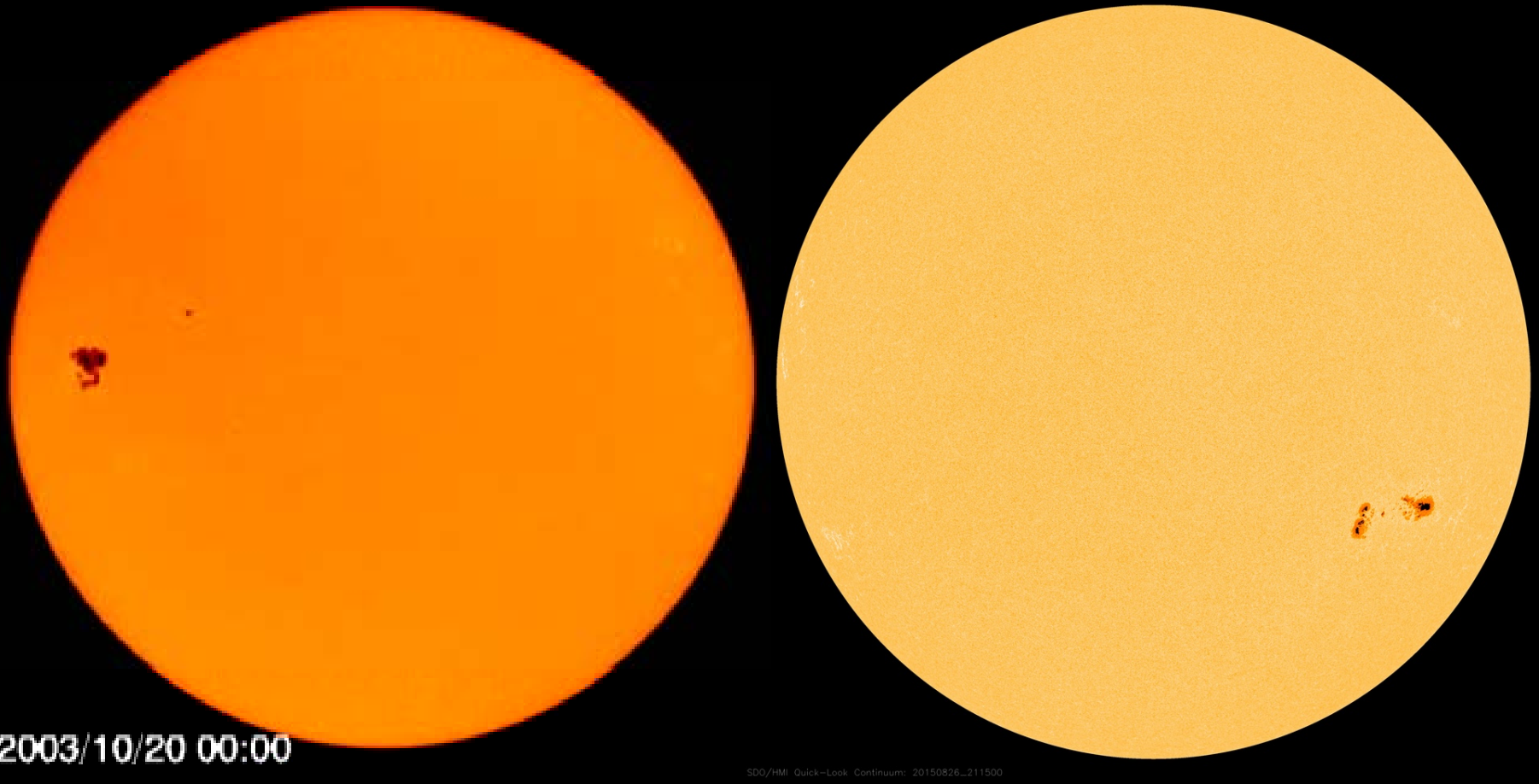
Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space and groundbased technological systems, as well as endanger human health.



Sunspots and the Solar Cycle

The Sun at Solar Maximum

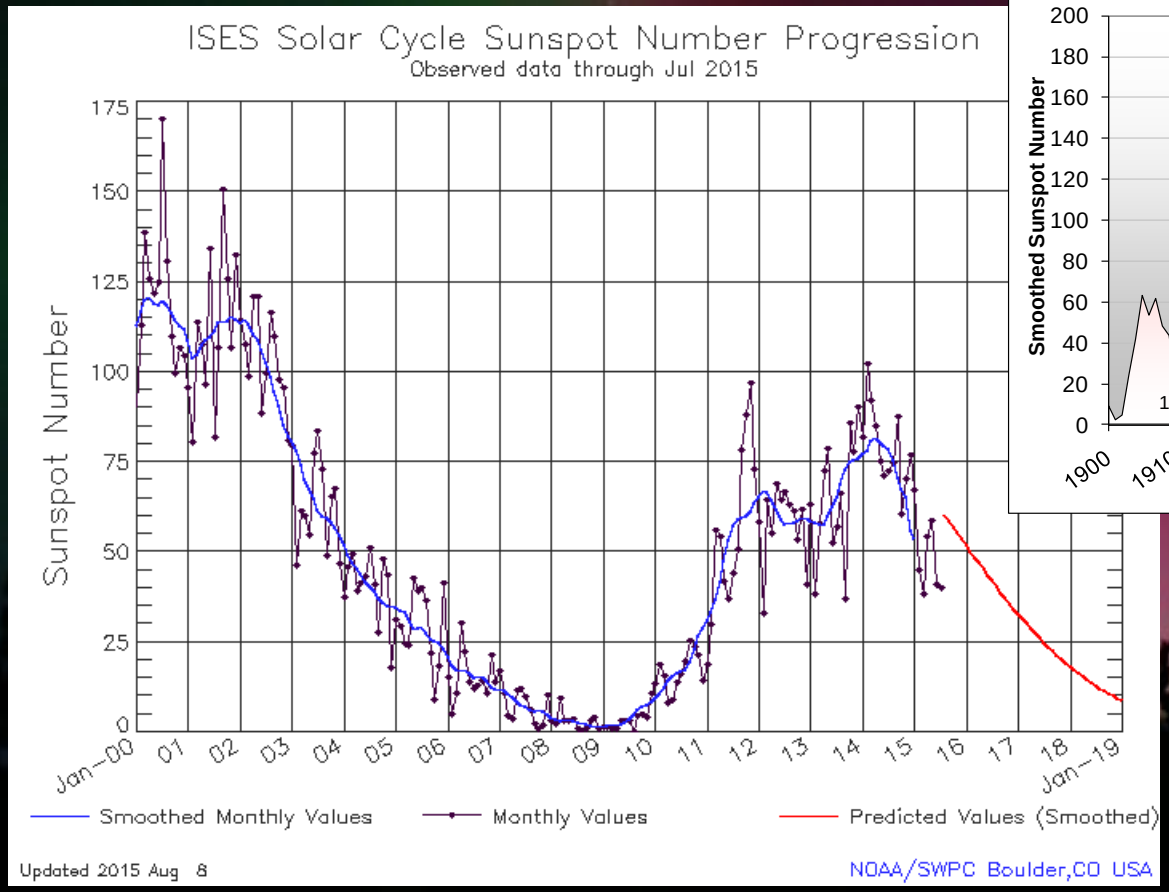
The Sun Today

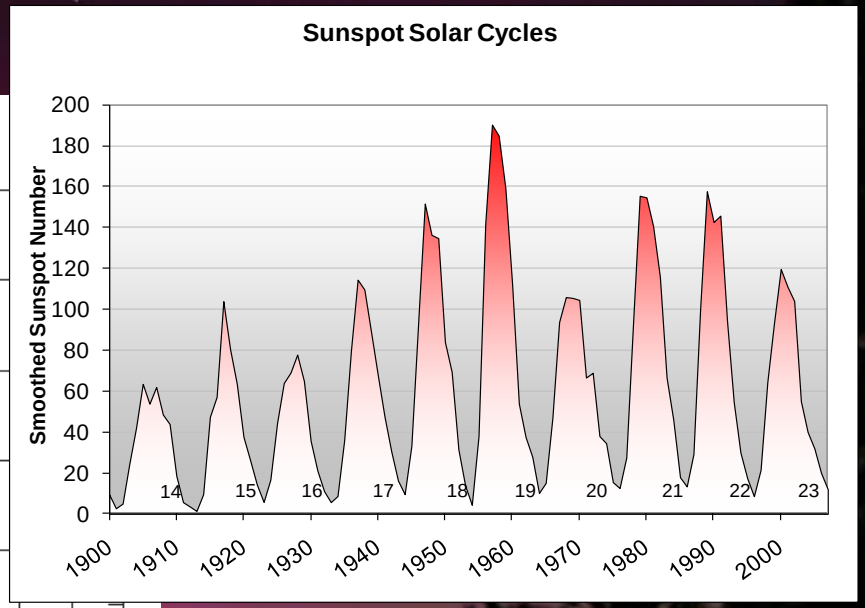


~27 day full rotation

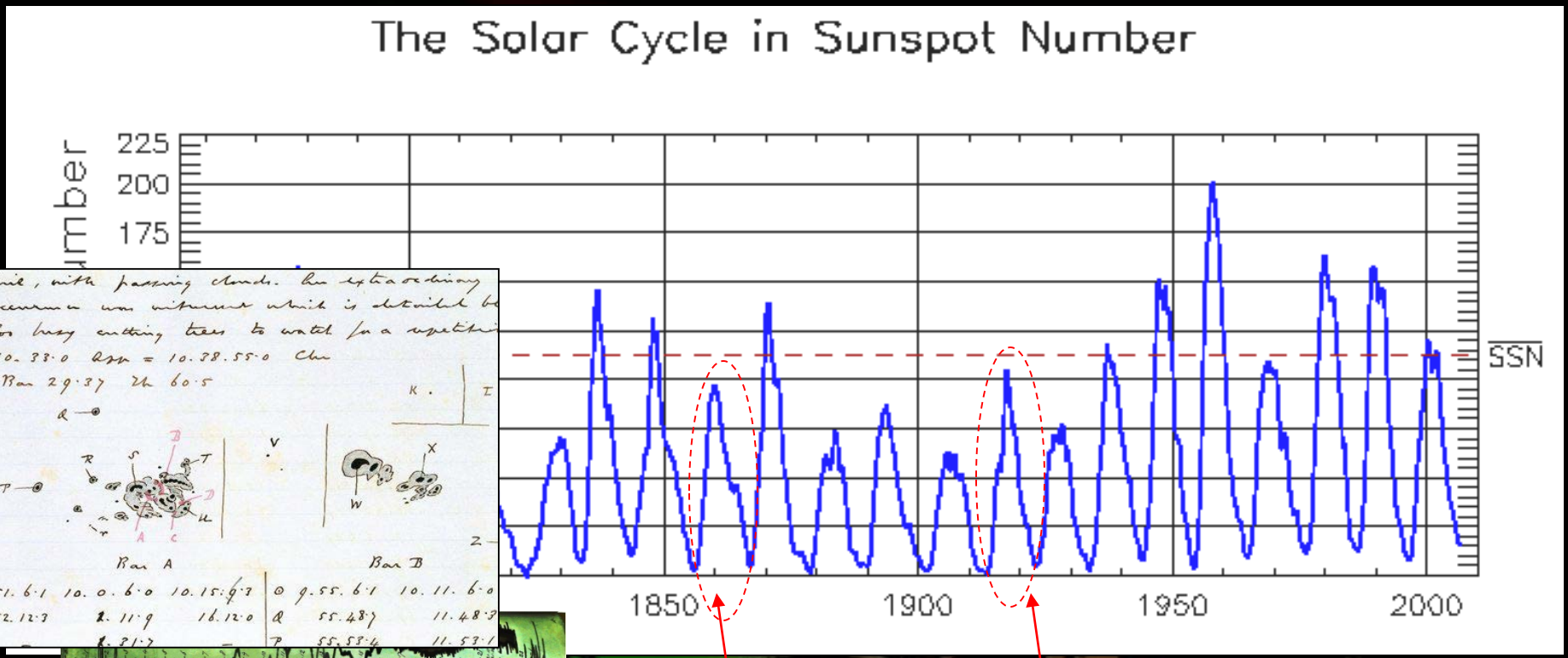
Solar Cycle Update

- **Cycle 23 began in May 1996**
- **Peak in April 2000 with SSN = 120**
- **Solar Minimum in December 2008**
- **Solar Cycle 24 Underway**

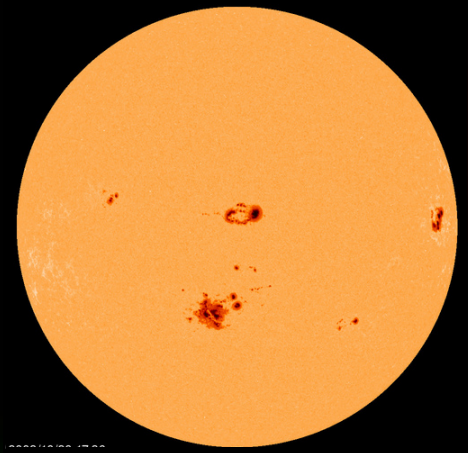


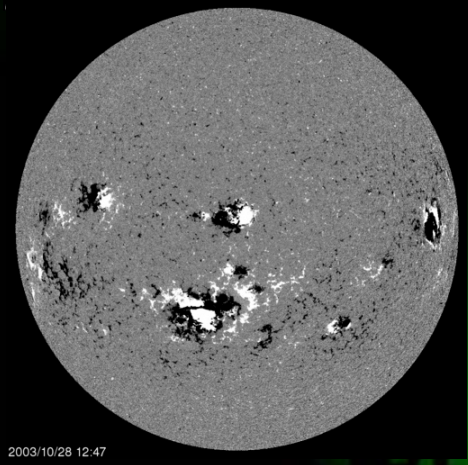


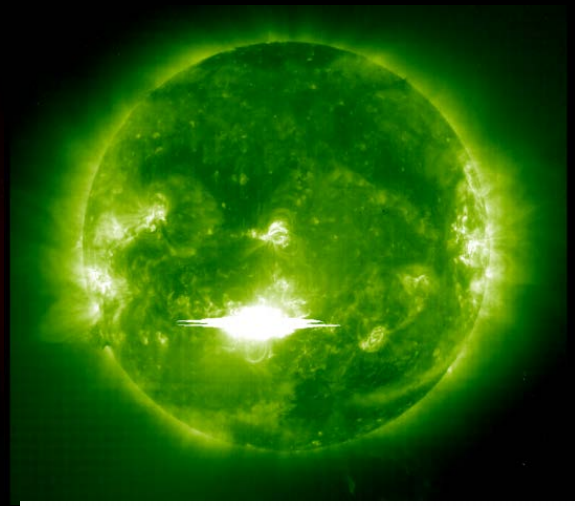
- Large geomagnetic storms can occur with smaller cycles
- The largest geomagnetic storms on record occurred during smaller than average cycles (no causality implied)

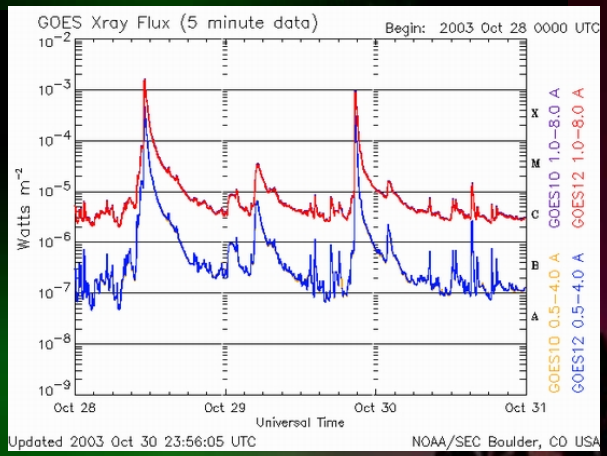


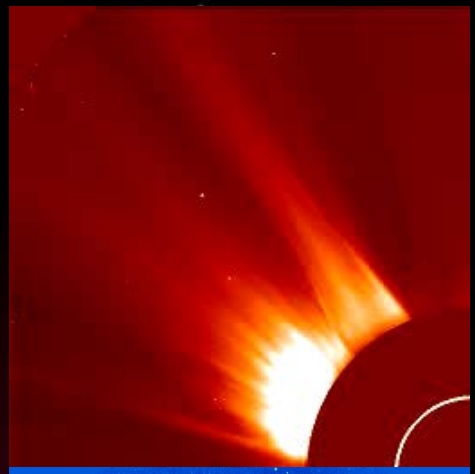
Sequence of Events

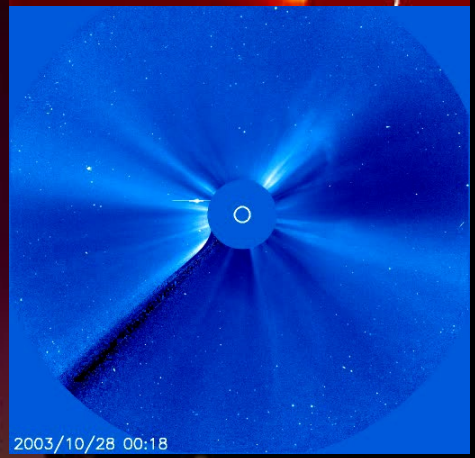












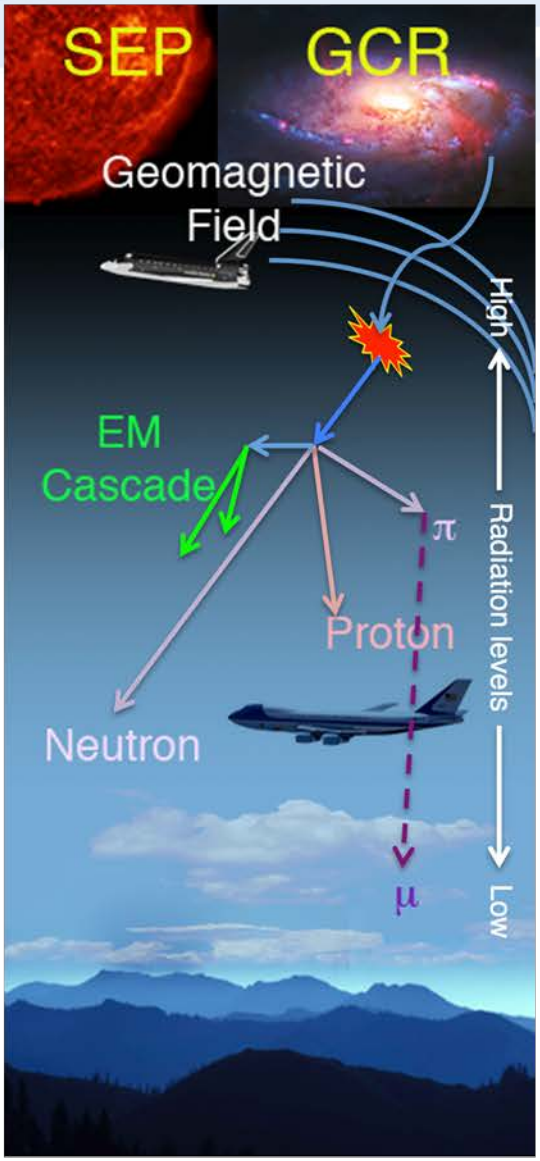
Conditions are Favorable for Activity (Probabilistic Forecasts)

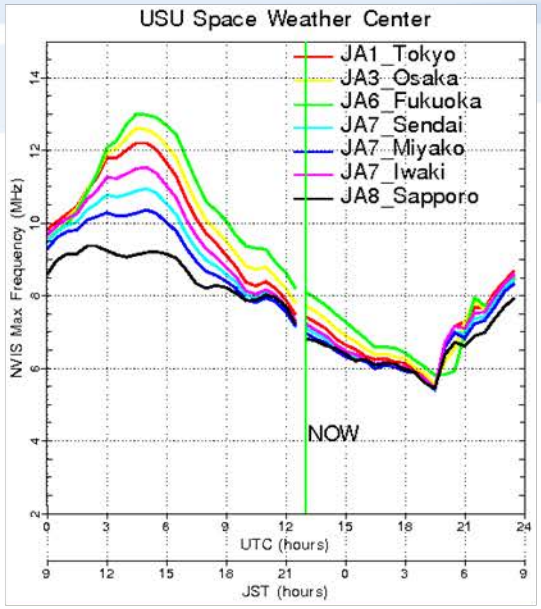
→

Event Occurs

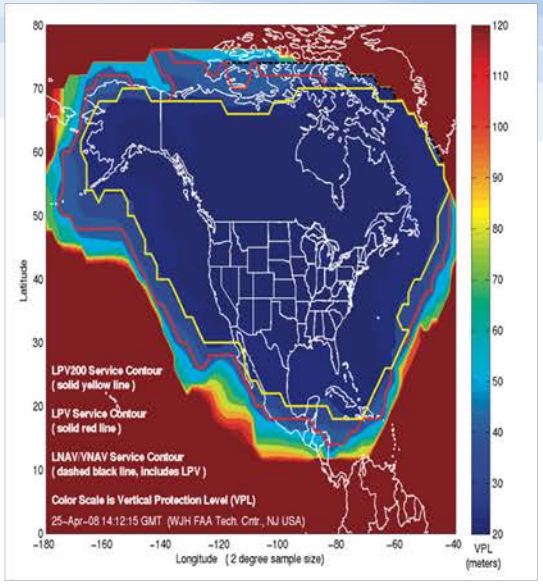
→

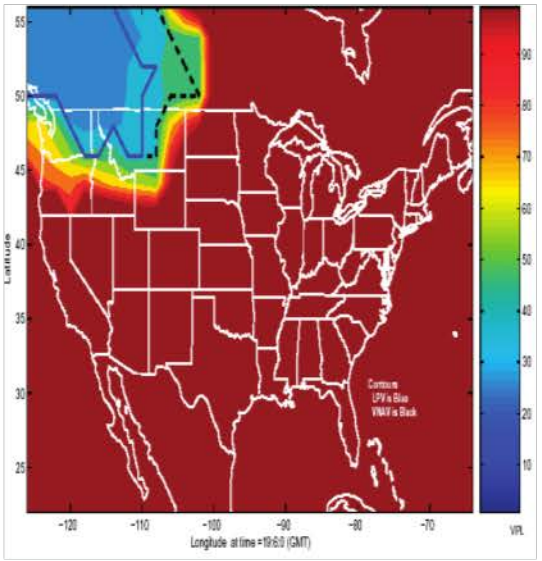
Coronal Observations


SEP
GCR
Geomagnetic Field
High
EM Cascade
π
Proton
Neutron
Radiation levels
μ
Low


USU Space Weather Center
JA1_Tokyo
JA3_Osaka
JA6_Fukuoka
JA7_Sendai
JA7_Miyako
JA7_Iwaki
JA8_Sapporo
NOW
NVIS Max Frequency (MHz)
UTC (hours)
JST (hours)


KEF
GAN
NYC
LGT
LAX
FRA


LPV200 Service Contour
(solid yellow line)
LPV Service Contour
(solid red line)
LNAV/VNAV Service Contour
(dashed black line, includes LPV)
Color Scale is Vertical Protection Level (VPL)
25-Apr-08 14:12:15 GMT (WJH FAA Tech. Cntr., NJ USA)
Latitude
Longitude (2 degree sample size)
VPL (meters)


Latitude
Longitude at time = 19:6:0 (GMT)
VPL

FAA

NextGEN

Phenomena Reference/Impacts

Solar Flare Radio Blackout (R Scale):

- No advance warning
- Effects lasts for 10's of minutes to several hours
- Impacts High Frequency (HF) communication on the sunlit side of the Earth
- First indication significant S and G scale activity may be possible

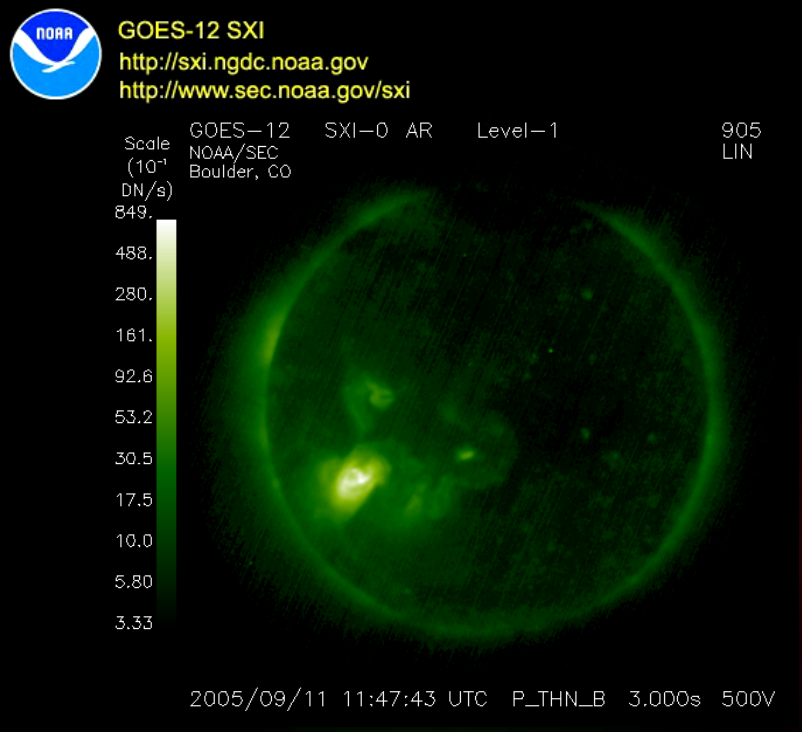
Solar Radiation Storm (S Scale):

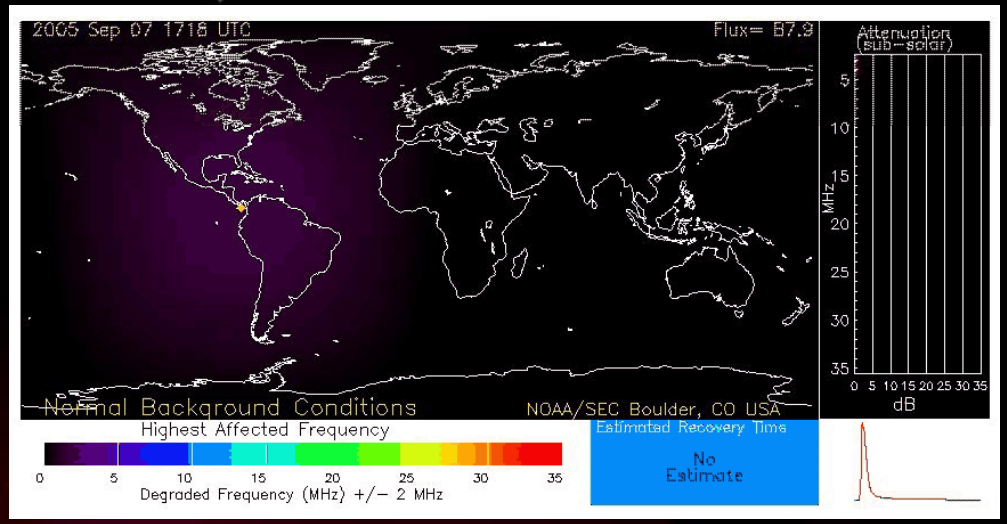
- Warnings possible on the minutes to hours time scale
- Elevated levels can persist for several days
- Impacts to the health and operation of satellites and International Space Station operations and crew
- Impacts High Frequency communication in the polar regions, affecting commercial airline operations

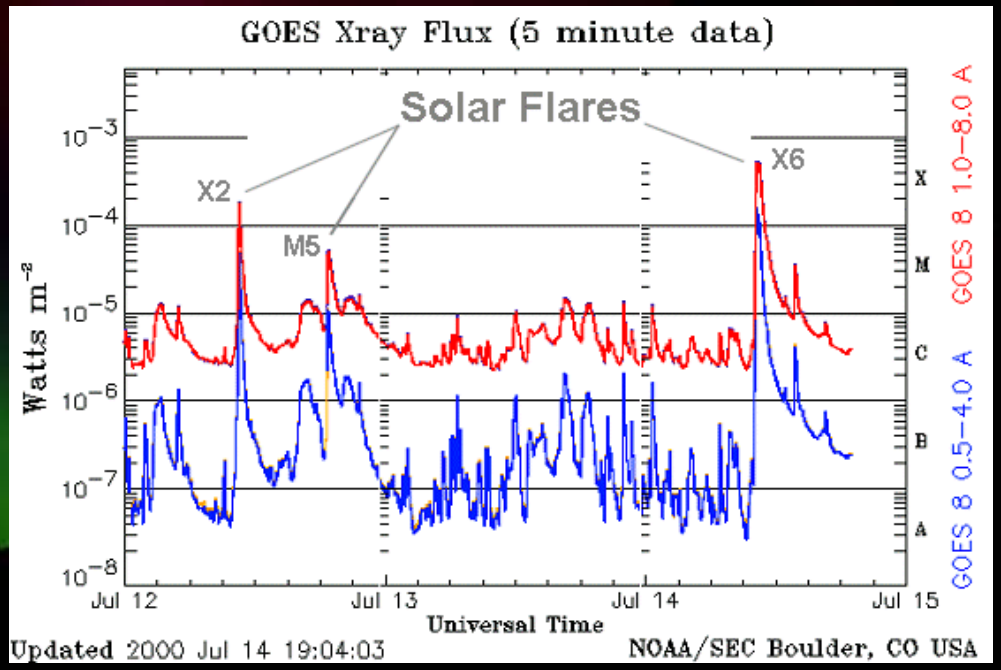
Geomagnetic Storm (G Scale):

- Advance notice possible given coronal mass ejection (CME) transit times from Sun to Earth range from just under a day to several days (CMEs being the main driver of significant storms)
- In extreme storms, impacts to power grid operations and stability
- Impacts to Global Positioning System (GPS) accuracy and availability
- Driver of aurora; severe to extreme storms may cause aurora to be visible over most of the mid latitudes

Solar Flares *(Radio Blackouts – R Scale)*





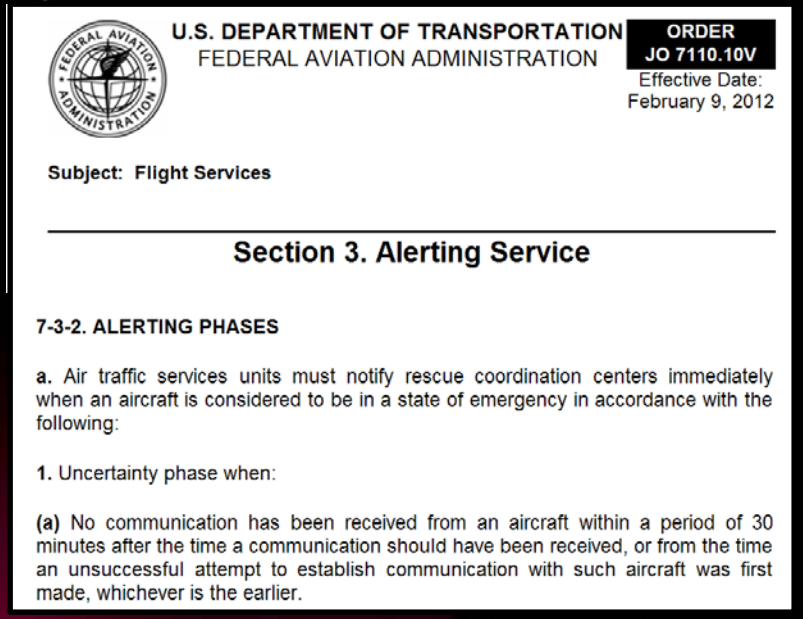


- Arrival: 8 minutes, photons
- Duration: Minutes to 3 hours
- Daylight-side impacts
- Probabilistic 1, 2, 3-day forecasts
- Alerts for exceeding R2 (only)
- Summary messages post-event

March 2012
Impacts on Aviation Comms

7 March 2012: INCERFA was issued for Air Canada 003 (Vancouver to Tokyo) until communications were established with the flight.

(INCERFA is issued when there is uncertainty as to the safety of an aircraft and its occupants.)



U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

ORDER JO 7110.10V
Effective Date: February 9, 2012

Subject: Flight Services

Section 3. Alerting Service

7-3-2. ALERTING PHASES

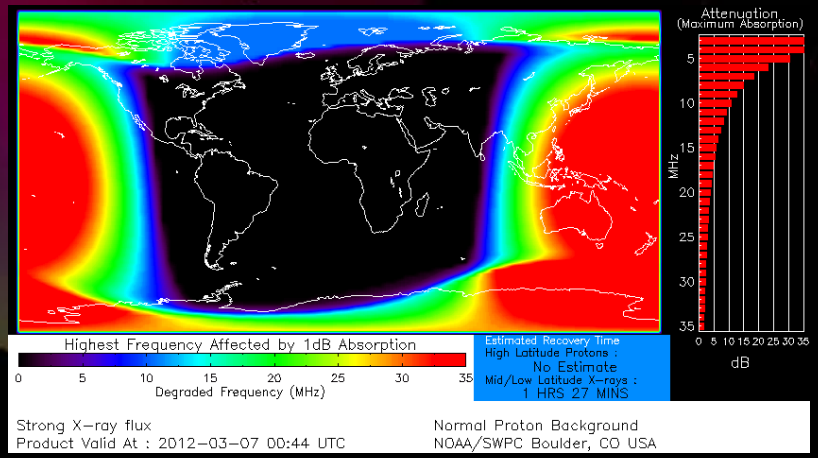
a. Air traffic services units must notify rescue coordination centers immediately when an aircraft is considered to be in a state of emergency in accordance with the following:

1. Uncertainty phase when:

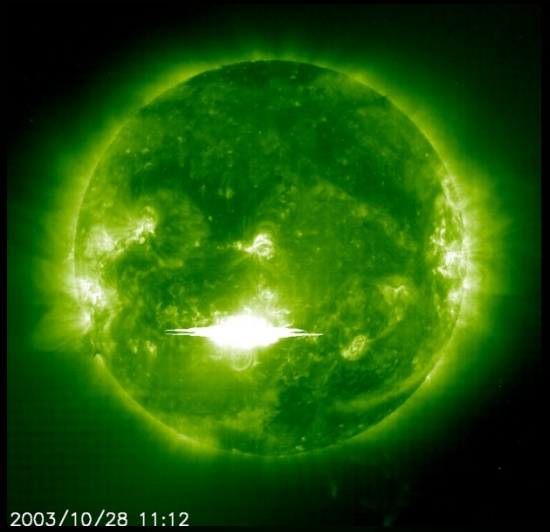
(a) No communication has been received from an aircraft within a period of 30 minutes after the time a communication should have been received, or from the time an unsuccessful attempt to establish communication with such aircraft was first made, whichever is the earlier.

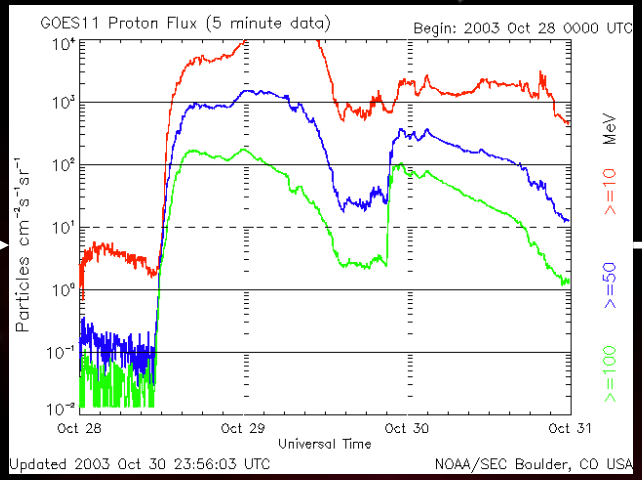
6-7 March 2012: "**Severe impact** at 2249Z initially affecting CWP *[Central West Pacific]* but by 2400Z, impact peaked and was affecting all communications. 25 ATC messages were delayed."

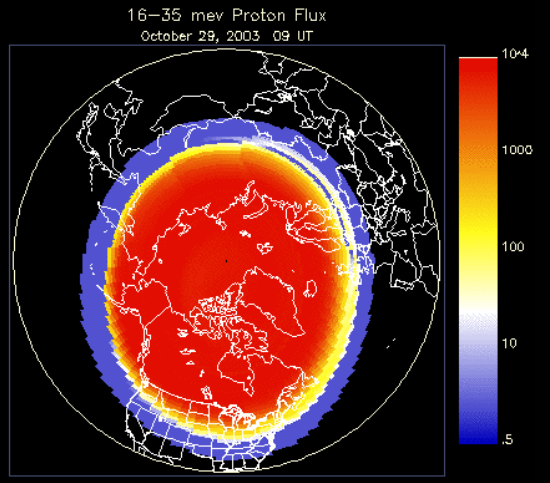
- Air Traffic Communications



Solar Radiation Storms *(S Scale)*





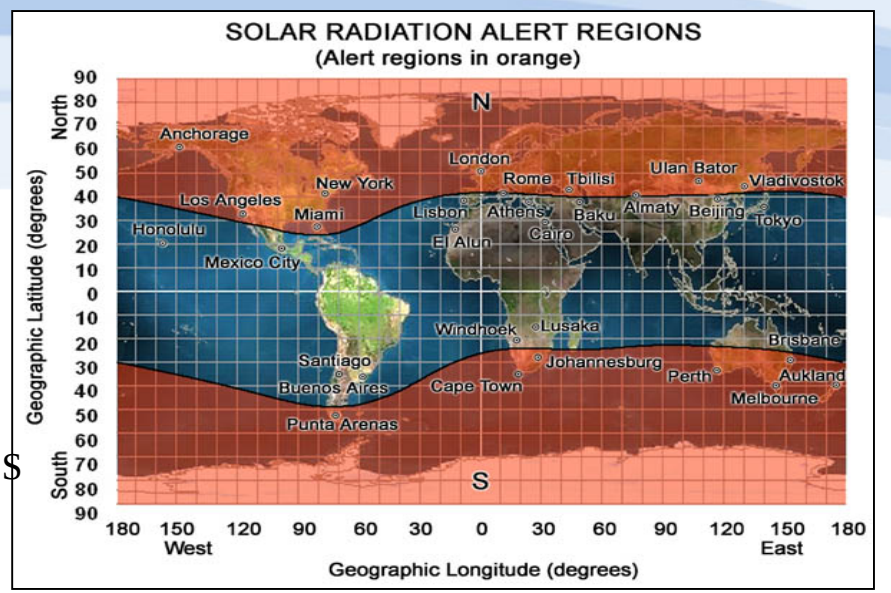


- Arrival: 10's of minutes to several hours
- Duration: hours to days
- Short-term warnings pre-onset
- Alert for threshold crossing
- Summary post-event

Space Weather Impacts to Aviation

1. **Aviation radiation exposure**
   - Galactic Cosmic Rays (GCR) background dose (long term career health)
   - Solar Energetic Particle (SEP) event dose (fleet operations and aircrew/passenger safety)
   - Flying polar routes (high or even midlatitude) during increased levels of radiation may result in an increase in exposure to harmful radiation
2. **Ground-to-aircraft radio communication disruption**
   - HF radio communication (transoceanic and polar routes)
   - Scintillation (rapid fluctuation of phase & amplitude of signal) outages for L-band, UHF, VHF, HF (satcom, radar, comm)
   - Radio blackouts are possible.
   - When Radio Communications are poor or non existent, flights must operate over less optimum routes
3. **WAAS GPS Navigation**
   - Increased location uncertainty (during landing and approaches)
   - Many aircraft are equipped with Inertial Reference Units which are dependent on Global Positioning Satellites (GPS)

Federal Aviation Administration (FAA) Radiation Alert



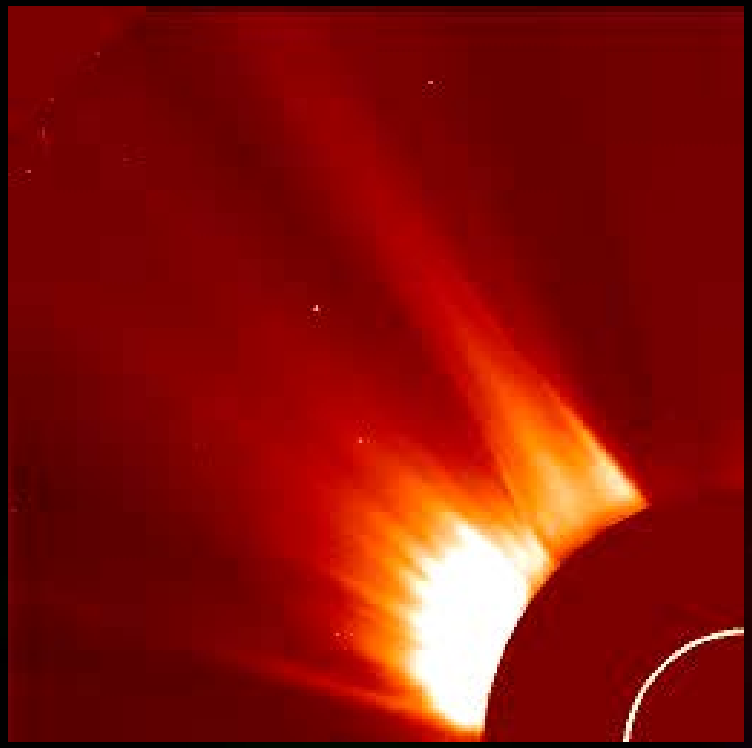
ALERT: SOLAR RADIATION ALERT AT FLIGHT ALTITUDES
CONDITIONS BEGAN: 2003 OCT 28 2113 UTC

COMMENT:
ATELLITE 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 (CGM) LATITUDES ABOVE 35 DEGREES NORTH, OR SOUTH.

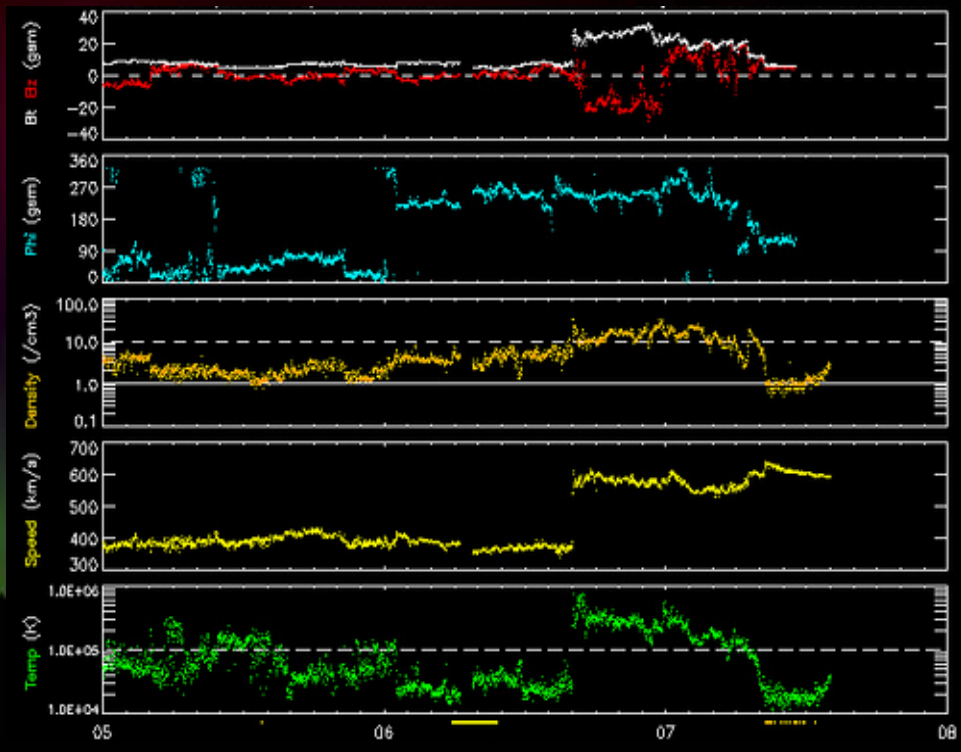
AVOIDING EXCESSIVE RADIATION EXPOSURE DURING PREGNANCY IS PARTICULARLY IMPORTANT.

REDUCING FLIGHT ALTITUDE MAY SIGNIFICANTLY REDUCE FLIGHT DOSES. AVAILABLE DATA INDICATES THAT LOWERING FLIGHT ALTITUDE FROM 40,000 FEET TO 36,000 FEET SHOULD RESULT IN ABOUT A 30 PERCENT REDUCTION IN DOSE RATE. A LOWERING OF LATITUDE MAY ALSO REDUCE FLIGHT DOSES BUT THE DEGREE IS UNCERTAIN. ANY CHANGE IN FLIGHT PLAN SHOULD BE PRECEDED BY APPROPRIATE CLEARANCE.

Geomagnetic Storms *(G Scale)*



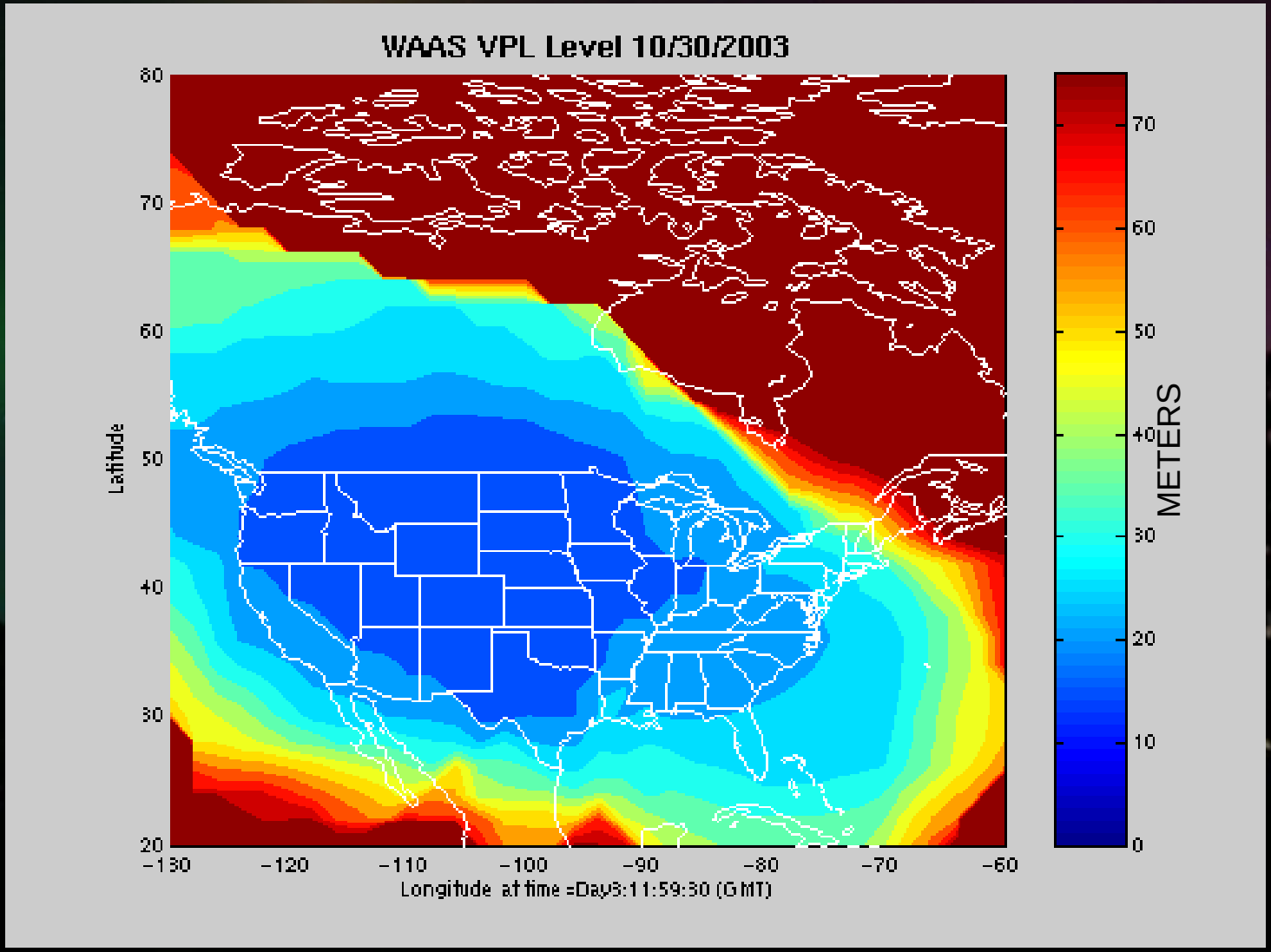
- Coronal Mass Ejections (CMEs) create geomagnetic storms
- Arrival: ~18 – 96 hours
- Duration: Hours to a day or two
- Creates ionospheric storms, geomagnetically induced currents, aurora



- 1-2 Day watch products based on coronagraph observations and modeling (Highest Expected K)
- Short-term (15 -60 min) warnings based on measurement at ACE spacecraft

GPS IMPACT – U.S. Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS)

- Intense geomagnetic and ionosphere storms occur on 29 and 30 Oct, 2003
- Acceptable vertical error limits were exceeded for 15 and 11–hour periods



Polar Region: Space Weather Above

- The geomagnetic field converges at the poles, creating a focal point for solar energetic particles

- As geomagnetic activity increases, the Aurora gets brighter, more active, and moves equatorward

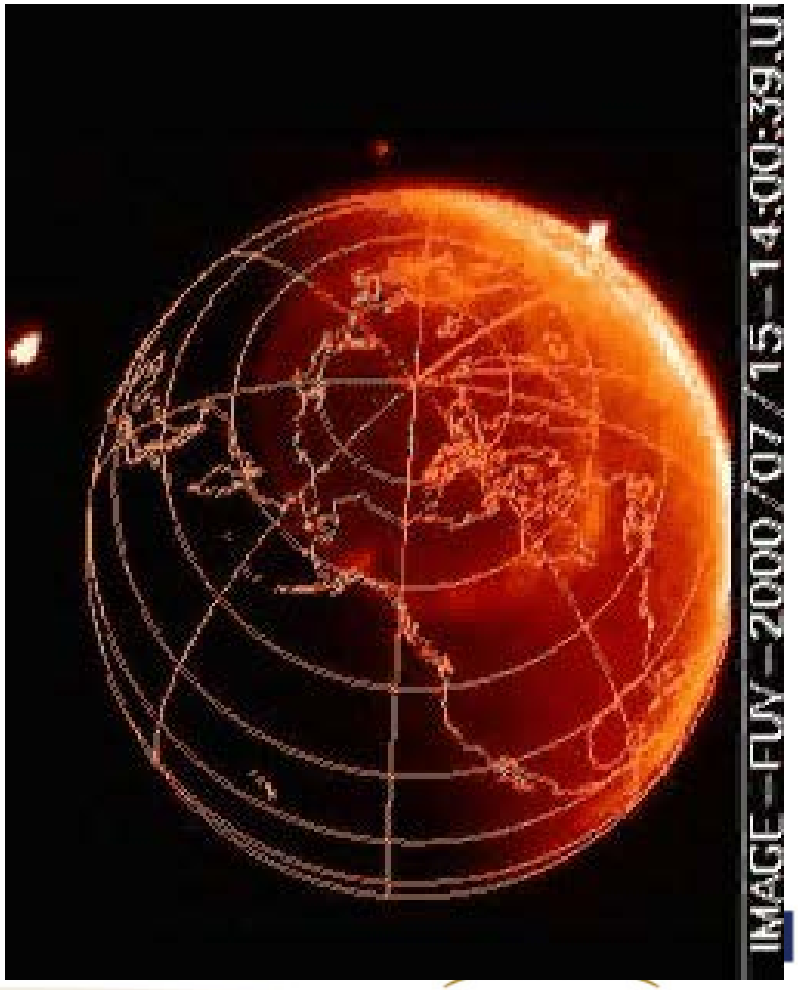
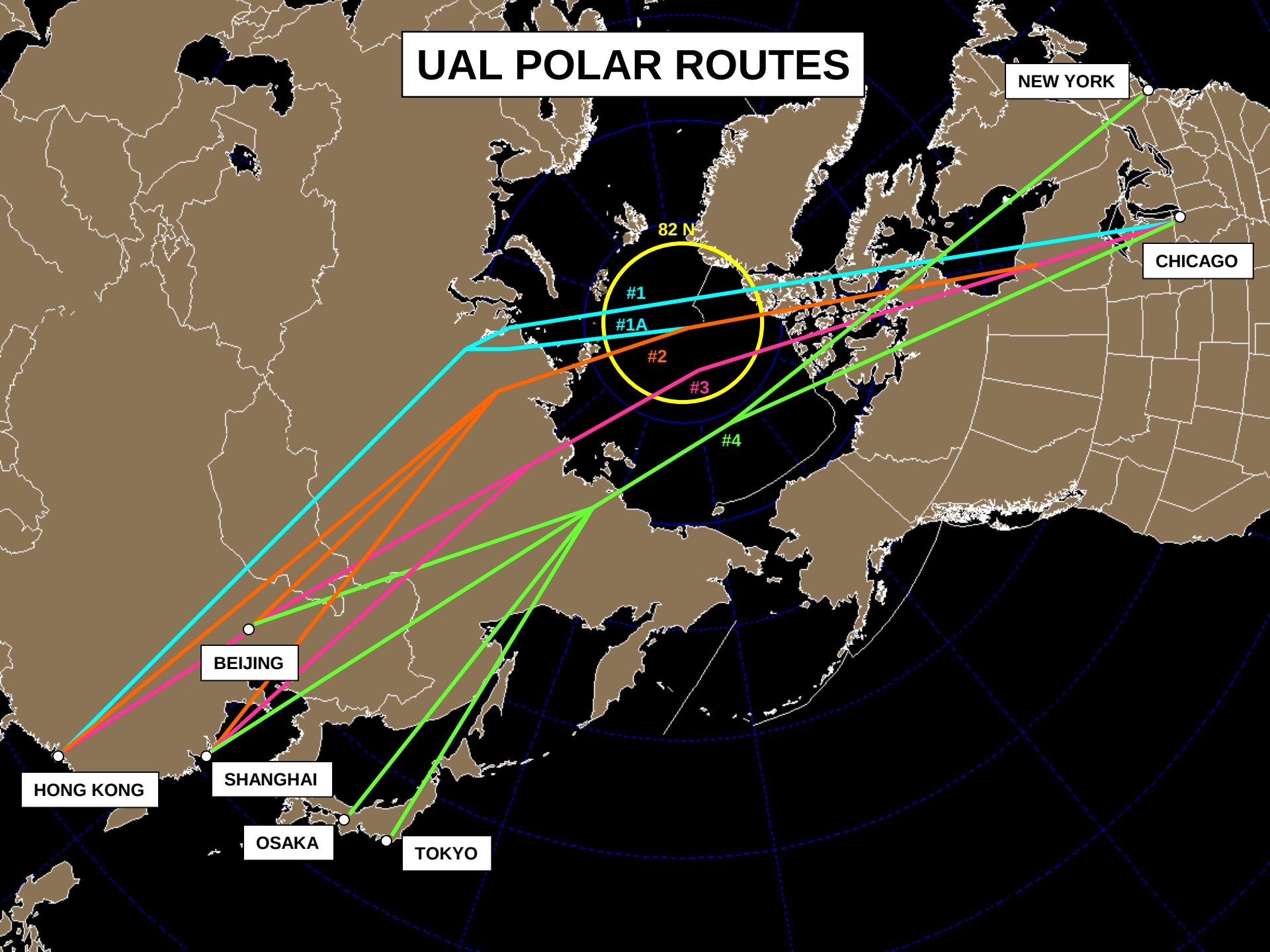
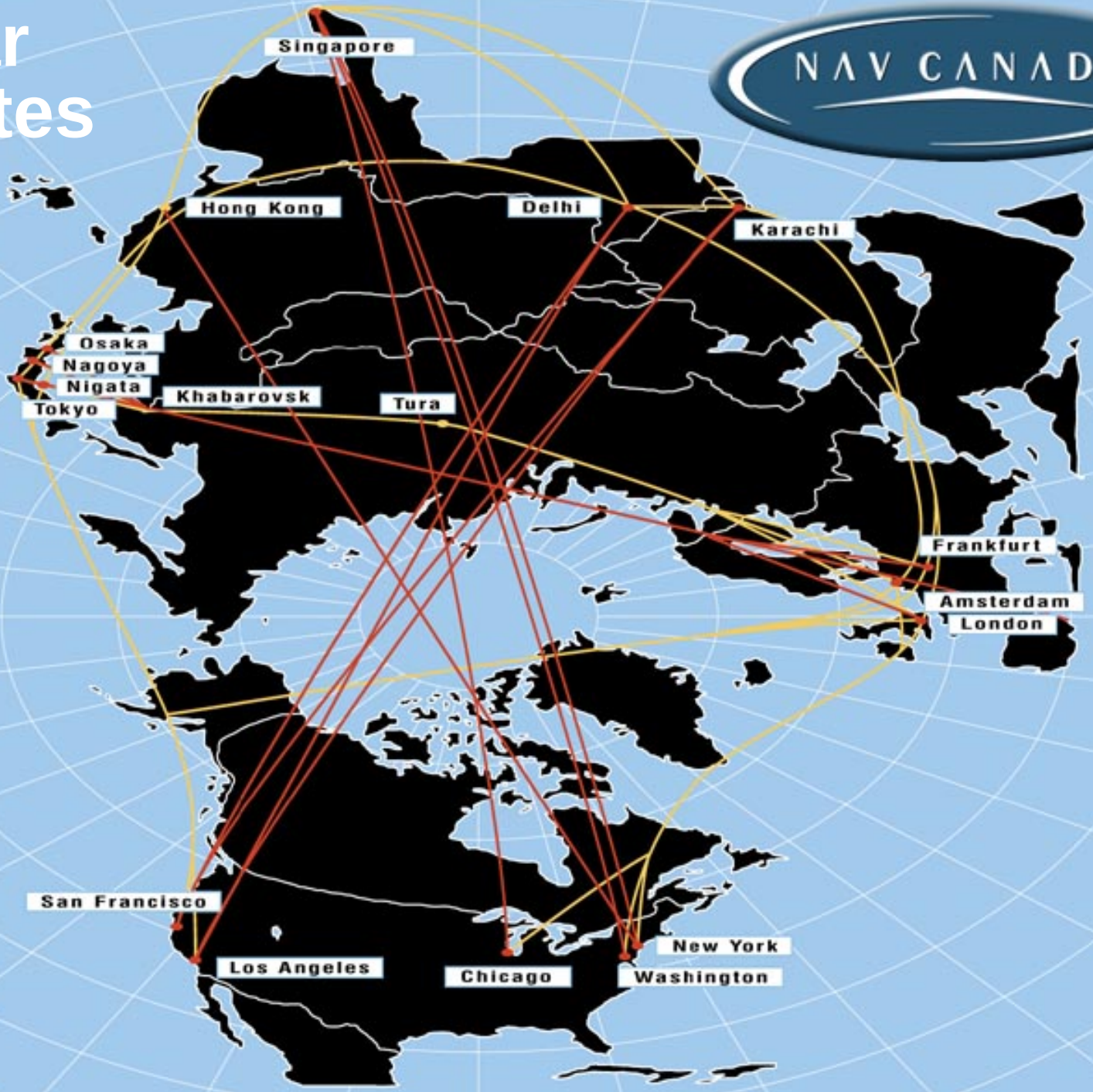


Image from NASA IMAGE Satellite

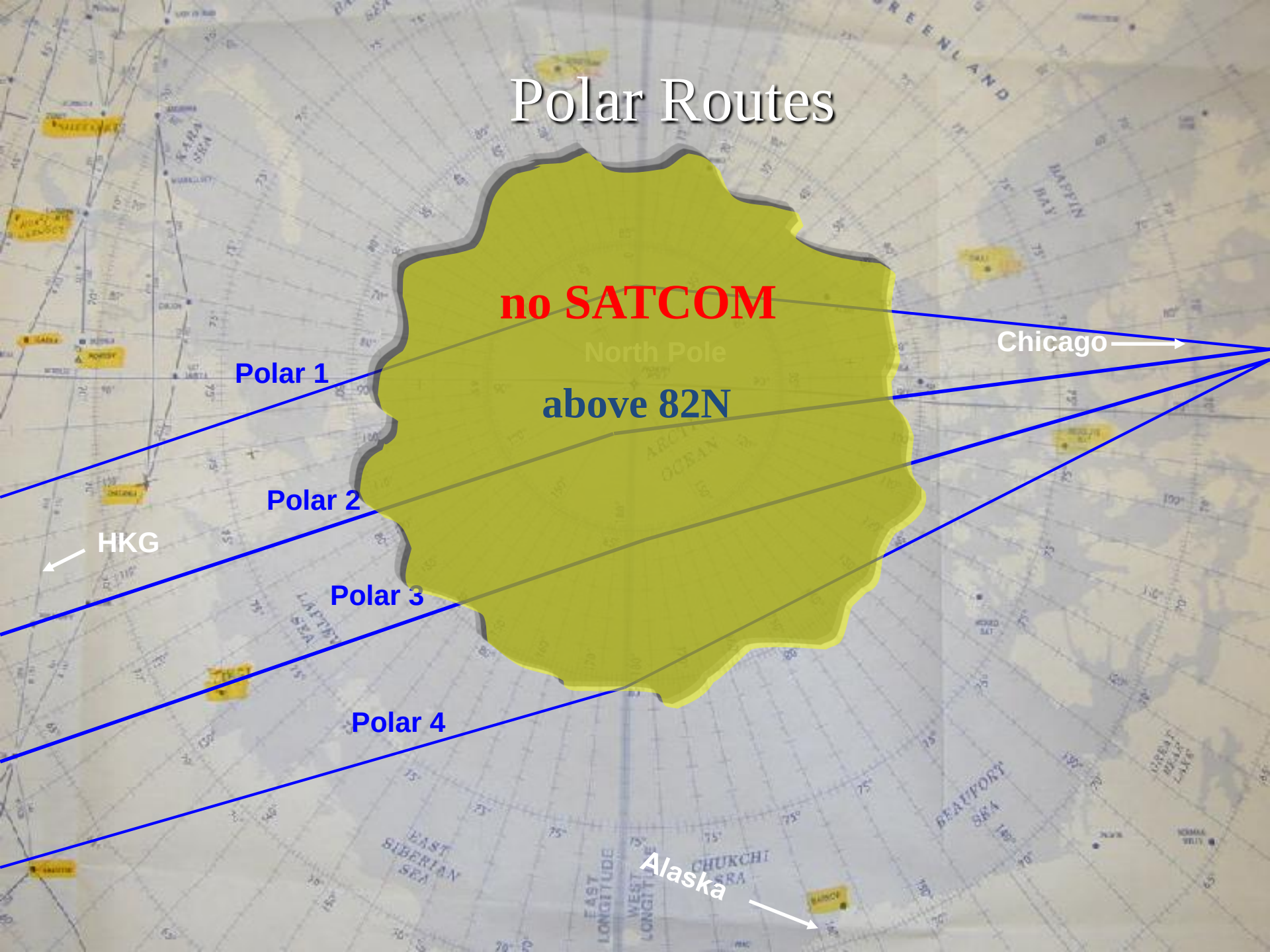
FAA


UAL POLAR ROUTES
NEW YORK
CHICAGO
82 N
#1
#1A
#2
#3
#4
BEIJING
HONG KONG
SHANGHAI
OSAKA
TOKYO

Polar Routes

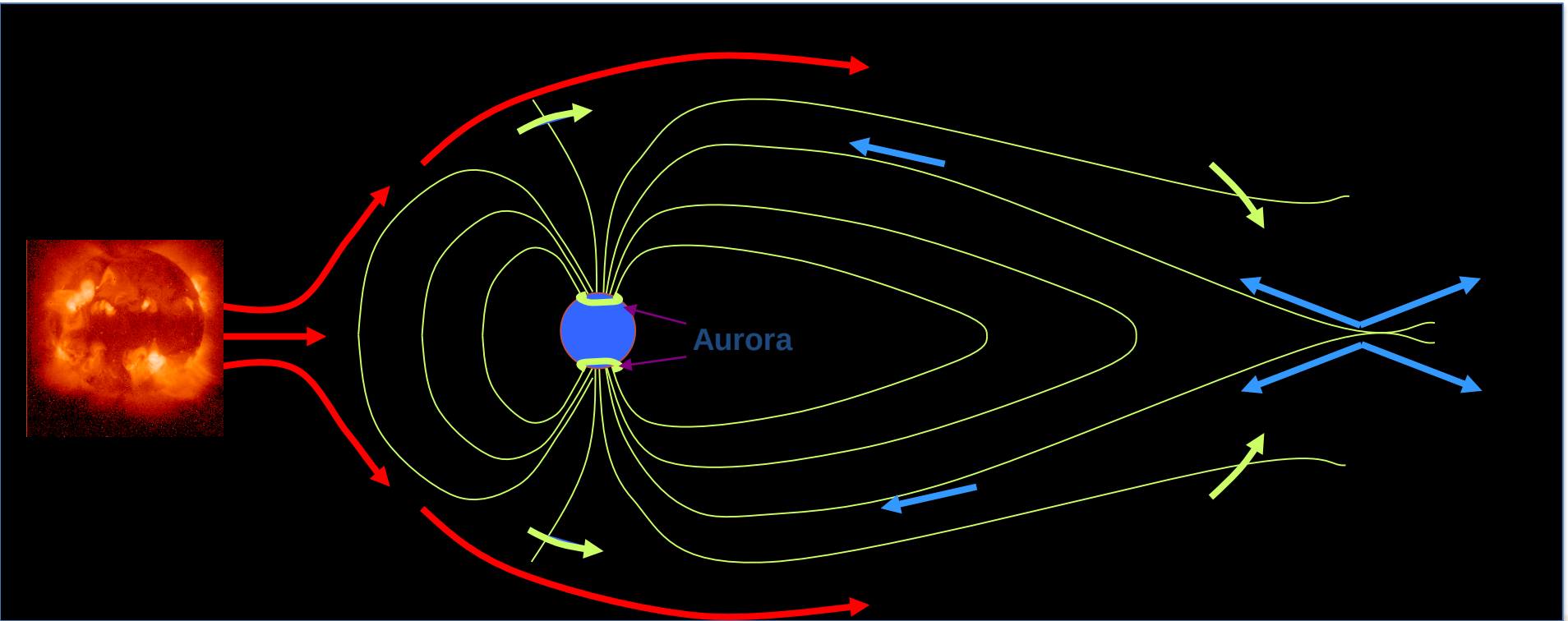


Polar Routes



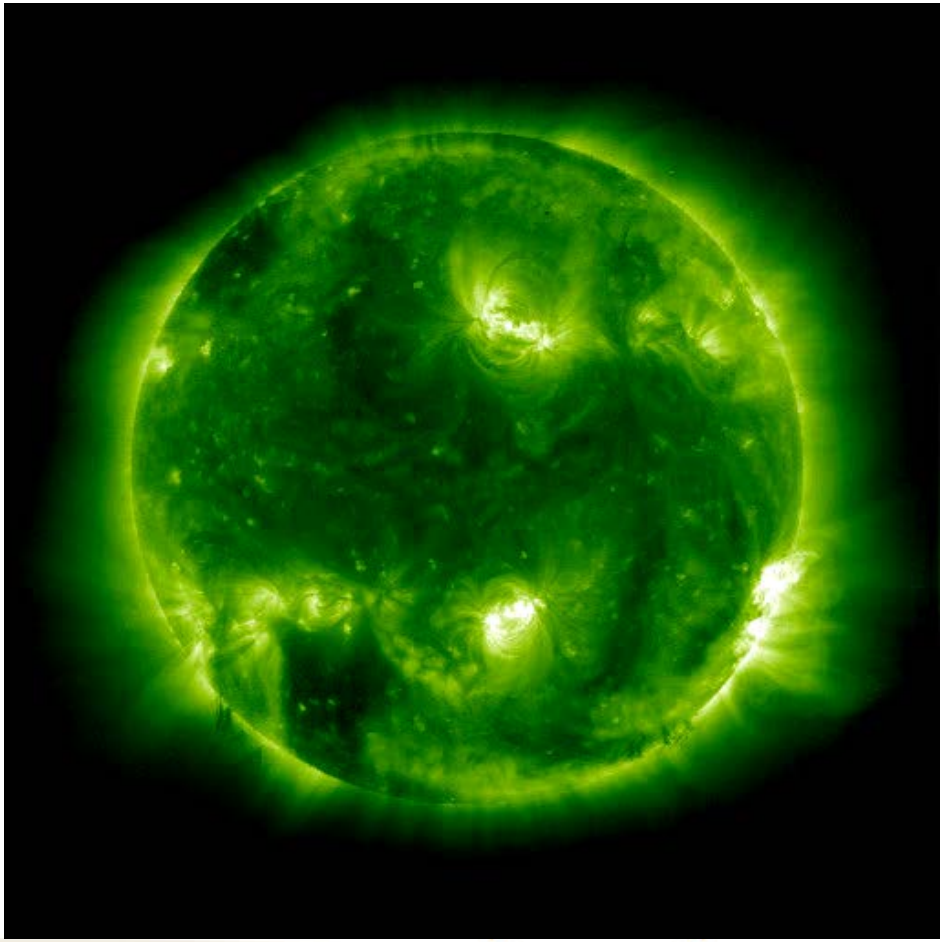
Magnetosphere

- Solar energetic particles have access closest to earth, due to the “dipole-like” configuration of the magnetic field
- These protons start a cascade that brings charged particles (causing HF outage) and neutrons (causing biological effects) to lower altitudes



Space Weather Storms
Timing and Consequences

- **A Flare and/or CME erupts from the Sun**
- **8 minutes later: First blast of EUV and X-ray light increases the ionospheric electron density**
  - Radio (HF) communications are lost
- **30 to 1000 minutes later: Energetic Particles arrive**
  - Astronauts are impacted
  - Satellites are impacted
  - Polar flights are impacted
- **1 to 4 days later: CME passes and energizes the magnetosphere and ionosphere**
  - Electric Power is affected
  - Navigation Systems are affected
  - Radio Communications are affected



FAA

Movie from NASA SOHO Satellite

Space Weather in ICAO

ICAO MET Divisional Meeting conjoint with WMO Commission for Aeronautical Meteorology (CAeM)-XV (July, 2014) Recommendation 2/7:

That an appropriate ICAO expert group, in close coordination with WMO, be tasked to develop provisions for information on space weather…

a) **requirements** for space weather information services consistent with the draft concept of operations for space weather information services;

b) **selection criteria and associated capability** for the designation of global and regional space weather centers, including the optimum number thereof;

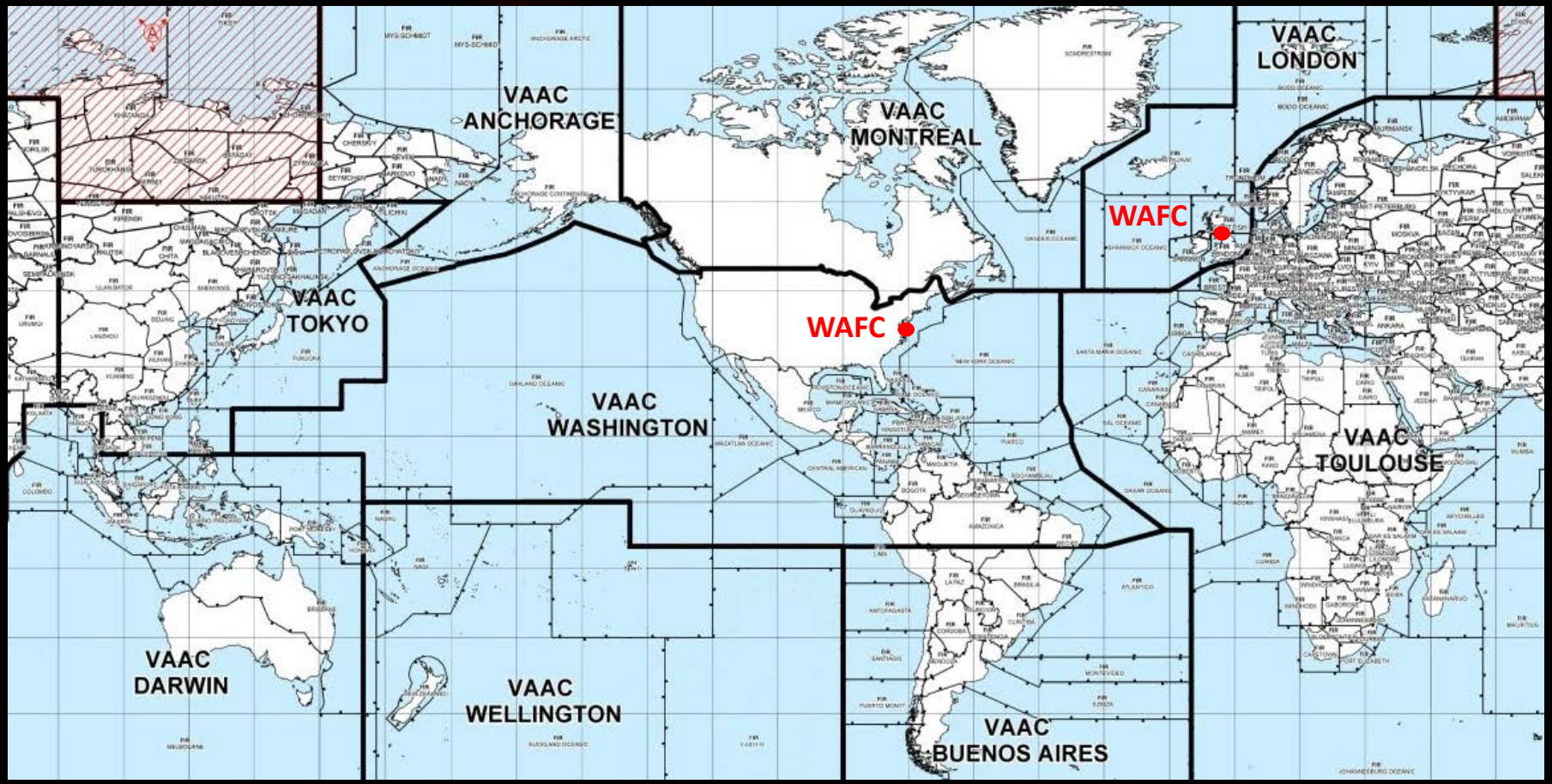
c) appropriate **governance and cost recovery arrangements** for the provision of space weather information services on a global and regional basis;

d) considerations on the use of space weather information and the various impacts space weather events could have on international air navigation

Inclusion of requirements in Amd. 78 (applicable Nov 2018) to ICAO Annex 3 – Meteorological Service for International Air Navigation and development of a Space Weather Manual

Challenges and Considerations

- Service delivery model – number of centers:
  - World Area Forecast Center (WAFC) model
  - Volcanic Ash Advisory Center (VAAC) model
  - Efficient blend of both…

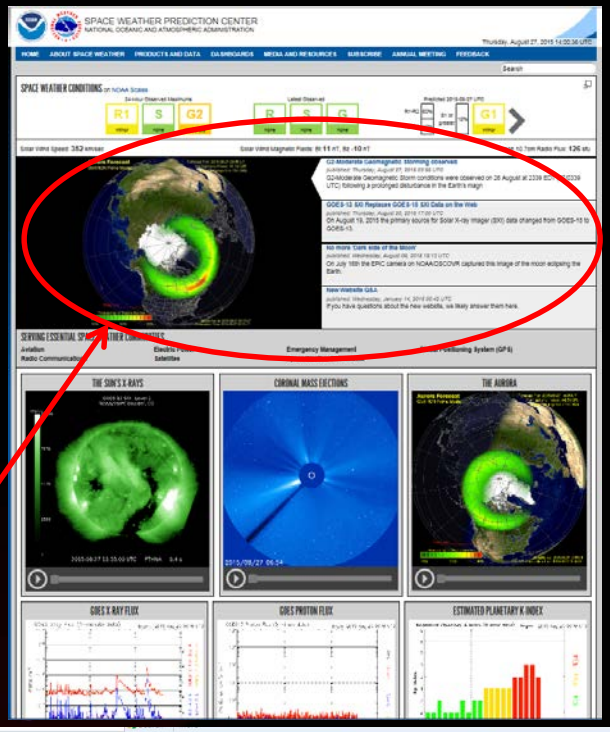


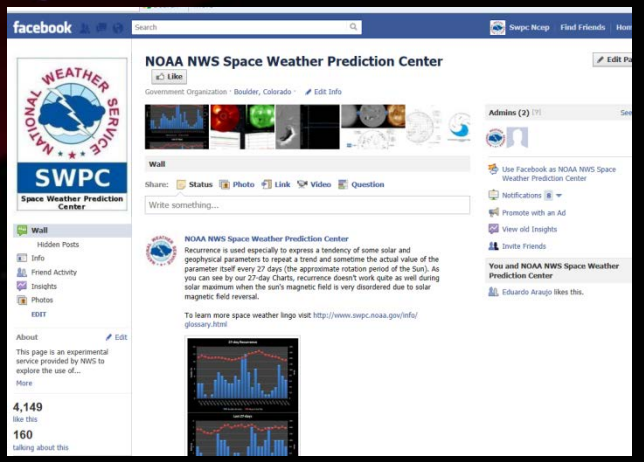
Challenges and Considerations

- Depending on model adopted, how are services harmonized and harmonized in a timely fashion?
- How is value added in a cost-effective way from multiple interpretations of largely the same global dataset?
- How are forecasters trained and competencies assessed?
- How do you strike the right balance between local or regional service provision and consistent global services?
- And in the end, how do you decide who provides these services?

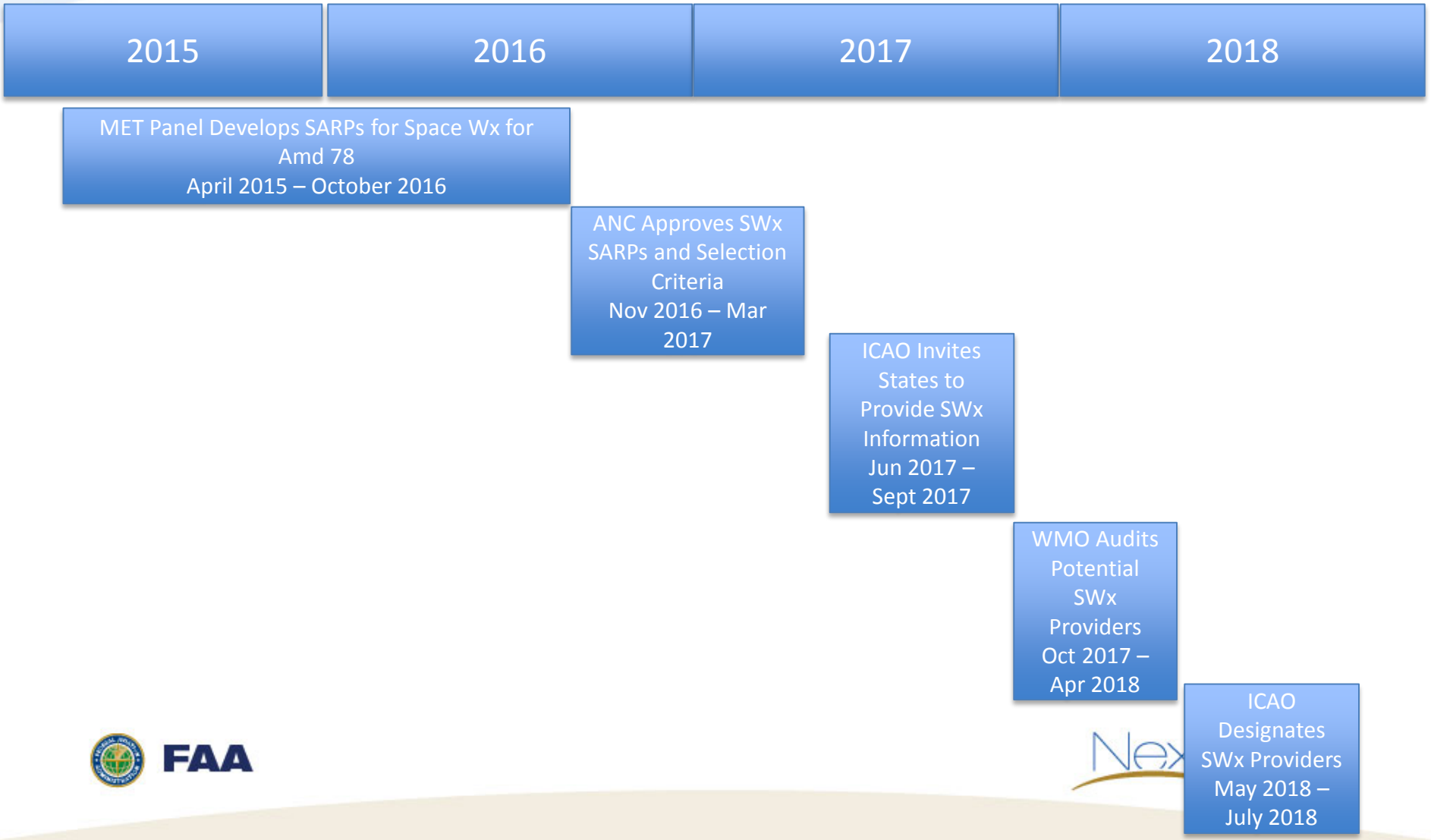
Information Dissemination

- Phone Contact for Critical Stakeholders: NASA, Commercial Airlines, Power Generation and Distribution, FEMA, etc.
- Product Subscription Service: Email-based, no cost subscription service open to all
- Website: Data, products, and models all available there. Tops News heading that will provide updates for elevated space weather
- Facebook: Active updates and education, secondary to official product dissemination means. Twitter in work.
- Active Media Support during significant events





Background - Timeline



FAA

Background - SARP

- Oct 2016 METP/2 endorsed draft SARPs in Amendment 78 to Annex 3 for SWX provision
  - ANC approved the draft SARPs and recommended inclusion of Space Weather Advisory in Annex 3
  - ANC accepted METP criteria and process for selecting SWX Provider(s)/Center(s) (more later)
  - ANC did not accept METP plan to implement global space weather provision first and then returning later with regional provision implementation
  - ANC directed METP to recommend the optimum number of SWX Centers (within timeline of selection)
    - Expect completion at WG-MISD July 2017 meeting
    - Requires METP endorsement at an extraordinary METP meeting

Background – Provider Selection

- Phases to designate ICAO SWX Provider(s)/Center(s)
  - ICAO issued State Letter on 9 June 2017 requesting interested States to respond
    - Response due by September 8th
  - WMO conducted an audit of all States indicating an interest in providing the SWX information
    - Audit against criteria developed by METP (accepted by ANC)
    - Did not asses the 'quality' of meeting criteria
    - Did not make a judgment (e.g., ranking) of States - only reported results of States' meeting or not meeting the identified criteria
  - Council will select/designate States to provide SWX Annex 3 products in July 2018
    - Based on 'optimum number' recommended by METP
    - Based on WMO audit results
    - Based on '*other'* considerations

Service Provision Model Discussion

Service Provision Model Discussion (Global)

Radiation – Global

Service Provision Model Discussion (Global)

Radiation – Global, Day-side HF

Service Provision Model Discussion (Global + 4) Regional)

Radiation – Global, Day-side HF, Polar HF and GNSS, Mid and Equatorial HF

Services Within ICAO

- Services proposed for inclusion in Amendment 78 to Annex 3
  - HF Communications (propagation, absorption)
    - HF COM
  - Communications via satellite (propagation, absorption) SATCOM
  - GNSS-based navigation and surveillance (degradation) GNSS
  - Radiation at flight levels (increased exposure)
    RADIATION
- Event-driven advisories for Moderate or Severe effects
- Applicability in November 2018
- Service model discussion still maturing

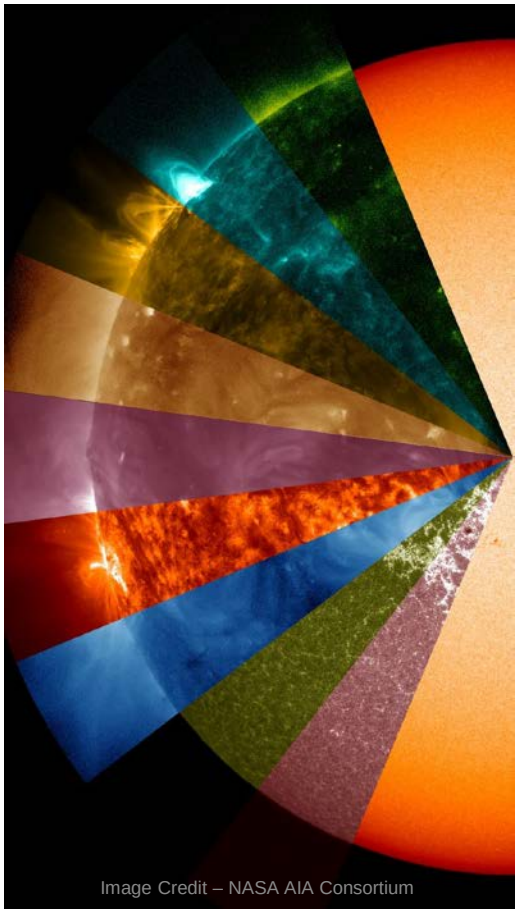


Image Credit – NASA AIA Consortium

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Services Within ICAO – Example Products

Example A2-4: Space weather advisory message (RADIATION effects)

(communication header)	
SWX ADVISORY	
DTG:	20161108/0000Z
SWXC:	(to be determined)
SWX EFFECT:	RADIATION MOD
ADVISORY NR:	2016/2
	20161108/0100Z HNH HSH E18000 – W18000 ABV FL350
	20121108/0700Z HNH HSH E18000 – W18000 ABV FL350
	20161108/1300Z HNH HSH E18000 – W18000 ABV FL350
	20161108/1900Z HNH HSH E18000 – W18000 ABV FL350
	20161109/0100Z NO SWX EXP
	RADIATION LEVELS HAVE EXCEEDED 100 PERCENT OF BACKGROUND LEVELS AT FL350 AND ABOVE. THE CURRENT EVENT HAS PEAKED AND LEVELS ARE SLOWLY RETURNING TO BACKGROUND LEVELS. SEE WWW.SPACEWEATHERPROVIDER.WEB
	NO FURTHER ADVISORIES

Example A2-3: Space weather advisory message (GNSS and HF COM effects)

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	GNSS MOD AND HF COM MOD
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z HNH HSH E18000 – W18000
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	LOW-LEVEL GEOMAGNETIC STORMING IS CAUSING INCREASED AURORAL ACTIVITY AND SUBSEQUENT MOD DEGRADATION OF GNSS AND HF COM AVAILABILITY IN THE AURORAL ZONE. THIS STORMING IS EXPECTED TO SUBSIDE

Services Within ICAO - Timeline

Schedule for Establishing Space Weather Information Capability

Start Date	End Date	Description	Responsibility
May 2017	June 2017	Issue State Letter requesting interest in providing the space weather information service.	ICAO
May 2017 September 2017	June 2017 October 2017	a) Request WMO assistance to evaluate candidate Provider States through site assessment visits and audits (without list of candidates States); and; b) Provide WMO with a list of candidates States.	ICAO
June 2017	September 2017	Respond to State Letter indicating ability to meet criteria for space weather information providers, including funding for site assessment visit and audit (to be conducted by WMO).	Candidate Provider States
October 2017	February 2018	Conduct site assessment visits and audits of candidate Provider States for space weather information capability.	WMO
March 2018	April 2018	Complete report to ICAO on candidate Provider States for space weather information capability.	WMO
April 2018	April 2018	Review of WMO audits report and recommend optimal number of space weather information providers.	METP
May 2018	June 2018	Review METP recommendations and provide proposals for designation of providers of space weather information for Council consideration.	ICAO ANC
June 2018	July 2018	Designate provider(s) of space weather information capability.	ICAO Council
July 2018	November 2018	Commence production and dissemination of space weather information.	Space Weather Provider(s)

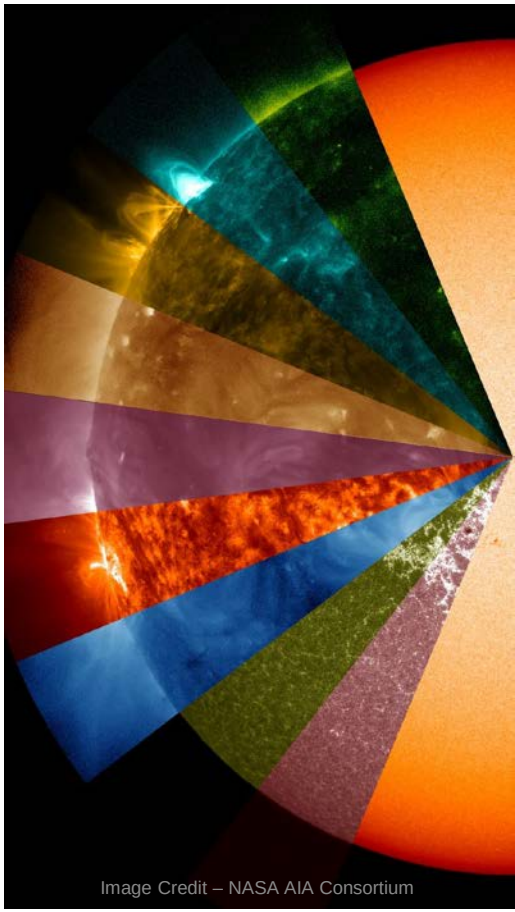

Image Credit – NASA AIA Consortium

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Current Capability

- **GNSS**
  - Nowcasting fairly mature where observational data is available
  - Skill improving in short-term forecasting (10's of minutes)
  - Longer range forecasts remain challenging, both pre-eruption and when awaiting commencement of a storm
- **Communications**
  - High Frequency (HF) blackout can be nowcast and forecast probabilistically
  - Limited skill in satellite communications, both in nowcast and forecast phases
  - Longer range forecasts remain challenging, both pre-eruption and when awaiting commencement of a storm as well

Situational Awareness & Impacts

- **Radiation**
  - In September, 2017 - “The solar storm we saw on September 10th was very strong… In a storm of this magnitude we will encounter increased radiation levels domestically”
  - Operations were affected, but should they have been? For a flight over the pole, timed to see all of the event, exposure *may* have been double the daily background
- **GNSS**
  - Augmentation systems generally monitor performance and shut down accordingly, but knowing that ahead of time may lead to different flight planning
- **Communications**
  - For the same September period, ATC in Miami had issues with lost communications for aircraft flying oceanic routes around Hurricane Irma. Lack of awareness caused confusion and exacerbated the situation

Evolution of Services and Future Needs

- **Radiation**
  - As aircraft fly farther and longer, exposures will increase
  - In situ observations will help with model validation, data assimilation, and operational decision making

- **GNSS**
  - Additional GNSS frequency adoption can largely eliminate ionospherically-induced position errors
  - Engineers with time and money can engineer around some challenges, but some will remain
  - Scintillation will likely remain the primary issue

- **Communications**
  - Application of HF is changing. HF datalink use still increasing…
  - Geosynchronous and LEO-based satellite communications evolving

- Short-term forecasting gains are coming in the 3-5 year timeframe. However, no paradigm shifts in longer-term forecasting are likely in the foreseeable future.

- **Given the chaotic, eruptive nature of the phenomena, space weather may never be like weather, but we can try…**

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Aviation Radiation Scientific Challenges

Nowcast

- Specification of input radiation spectrum
- Geomagnetic cutoff (fairly mature)
- Radiation transport
- Verification and validation!

Forecast

- Some skill in predicting decay, barring subsequent activity
- Low skill in onset or intensity
- Driven by eruptive phenomena that are incredibly hard to predict with any skill