Federal Aviation Administration

Concept of Operations for International Space Wx Information

Presented to: 9th Space Weather Symposium

By: Steve Albersheim, FAA (ANG-C6)

Mark Gunzelman, AvMet Applications Inc.

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WHY Space Weather Matters?

- **ICAO's Air Navigation Commission (ANC) tasked US-led ad hoc working group to develop SWx Requirements**
  - ICAO recognizes Space Weather (SWx) events as a potential hazard to Aviation operations
  - ICAO responsible for establishing standards for a service for Air Navigation
  - ICAO intends to update the Weather Annex for SWx impacts, products and procedures in support of aviation operations
  - ICAO ANC tasked the International Airways Volcanic Ash Watch Operations Group (IAVWOPSG) to develop set of draft *Operational Requirements for SWx*
    - IAVWOPSG has SWx oversight for ICAO

Problem Statement

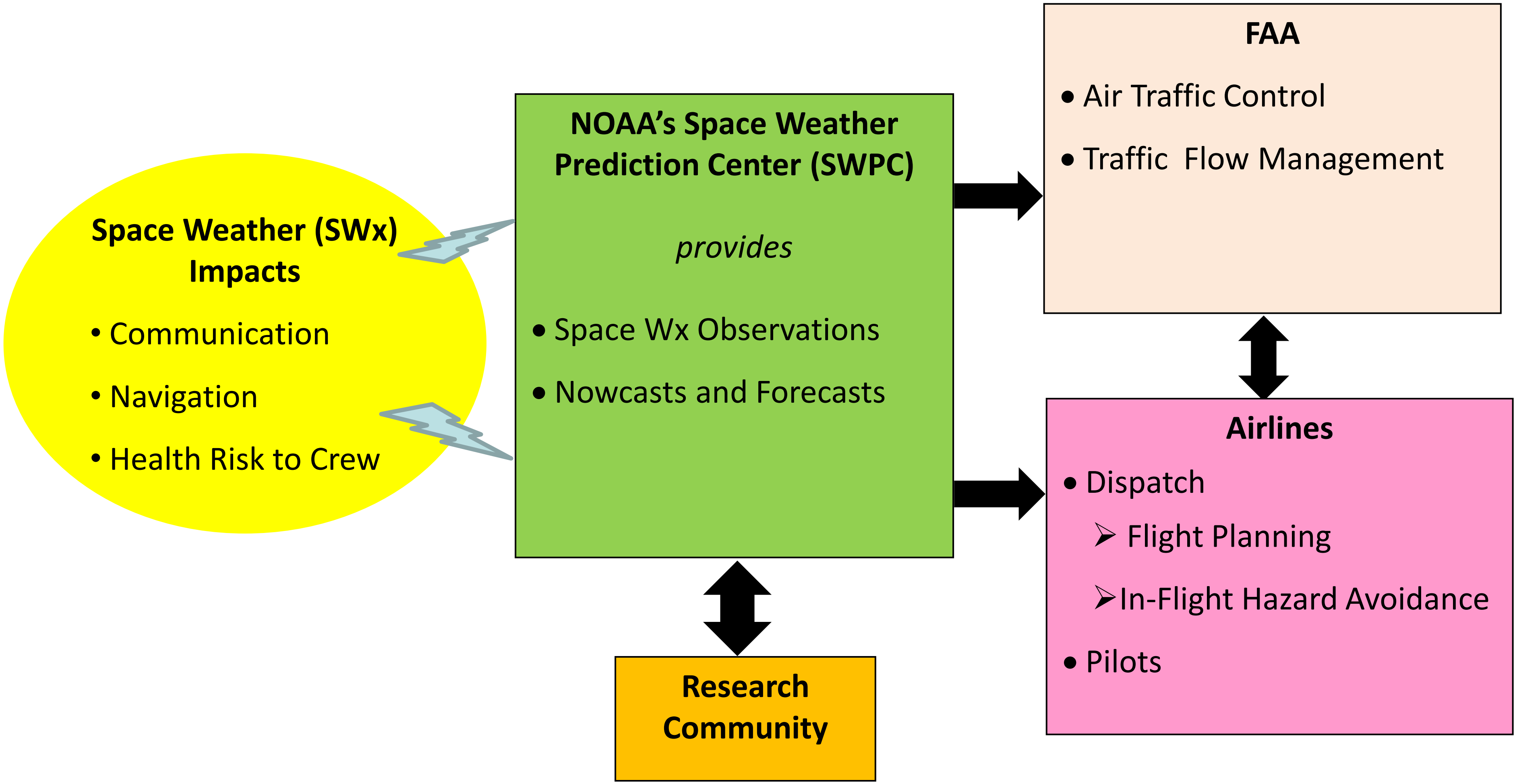
- **Space Weather phenomena adversely impact operations in polar airspace reducing capacity of polar routes**
  - Space Wx phenomena can cause:
    - Loss of communications capability
    - Erroneous navigation information and/or display
    - Crew and passenger radiation exposure (unknown health impacts)
  - Space Wx phenomena can constrain use of polar routes:
    - Flight Delays and Diversions
    - Less Efficient Routes Flown
  - Overall consequences are increased fuel consumption resulting in higher operating costs

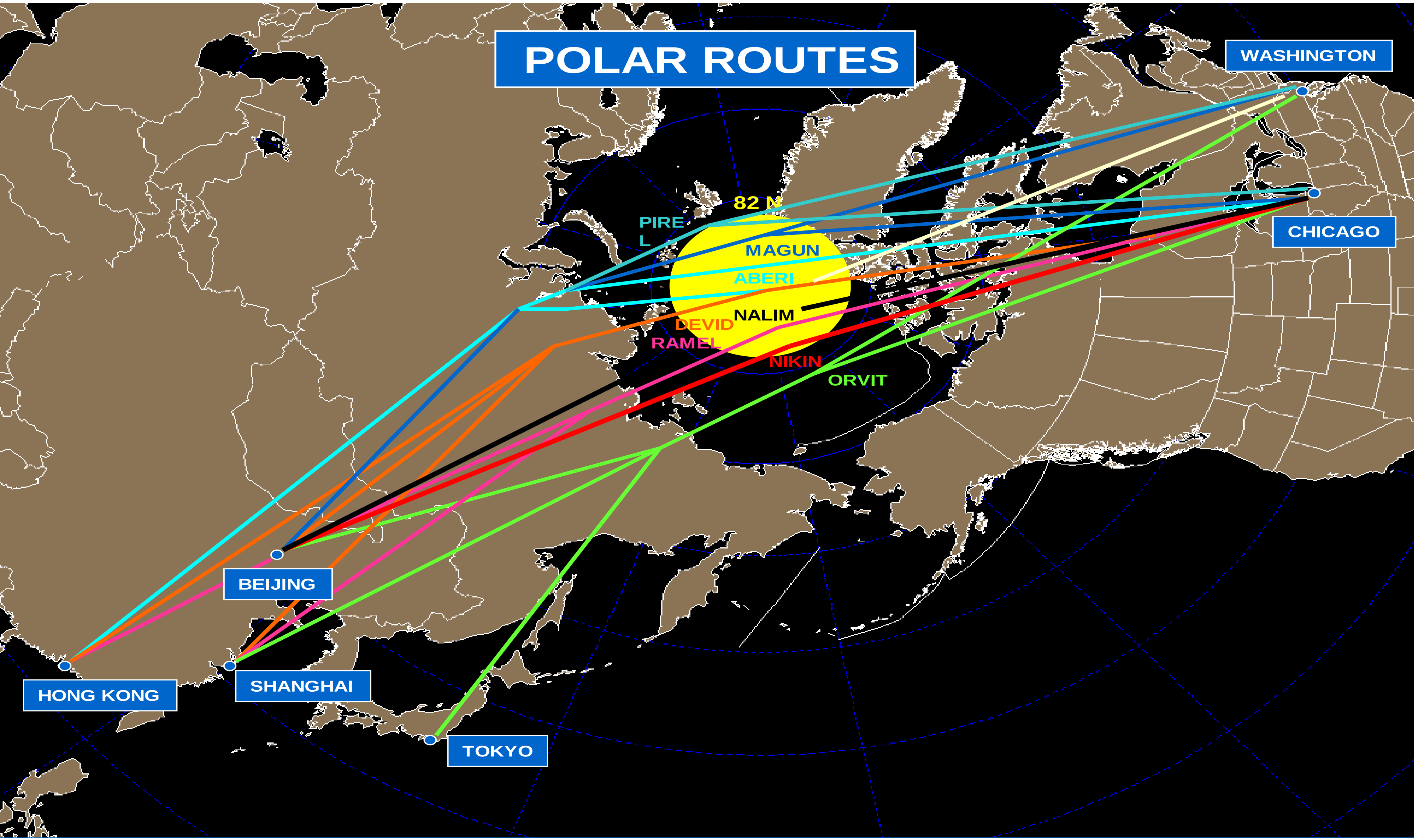
Aviation Users' Needs (AUNs)

- Define the impacts of space weather
- Provide the following types of information: observations, forecasts, and climatology
- Provide information in text and graphical format
- Present information using standardized format and content
- Describe/display the severity of impact in standardized text and graphical reports
- Provide text and graphical reports using specified timelines and durations
- Provide an estimate of the accuracy of the information
- State the regions affected
- Utilize stated transmission methods for space weather reports
- Provide information on disruptions to HF communications
- Provide information on disruptions to VHF communications
- Provide information on disruptions to UHF communications
- Provide information on fading and loss of lock to SATCOM
- Provide information on the radiation environment that will affect avionics
- Provide information on the radiation environment that will affect humans
- Provide Information on the accuracy and availability that will affect GNSS
- Define space weather information and decision-maker matrices
- Define communication and integration of space weather information
- Provide space weather education and training
- Use global standards for space weather information

Space Weather Sub-Group of the Cross Polar Working Group, "Integrating Space Weather Observations & Forecasts into Aviation Operations, Aviation Space Weather User Requirements" (Version 3.02, November 2010).

FLOW of SPACE WEATHER INFORMATION





Using polar routes for air traffic necessitates high-frequency radio communications at high latitudes (circular area toward center of figure), which can be disrupted by solar activity. SOURCE: Michael Stills, United Airlines, “Polar Operations and Space Weather,”

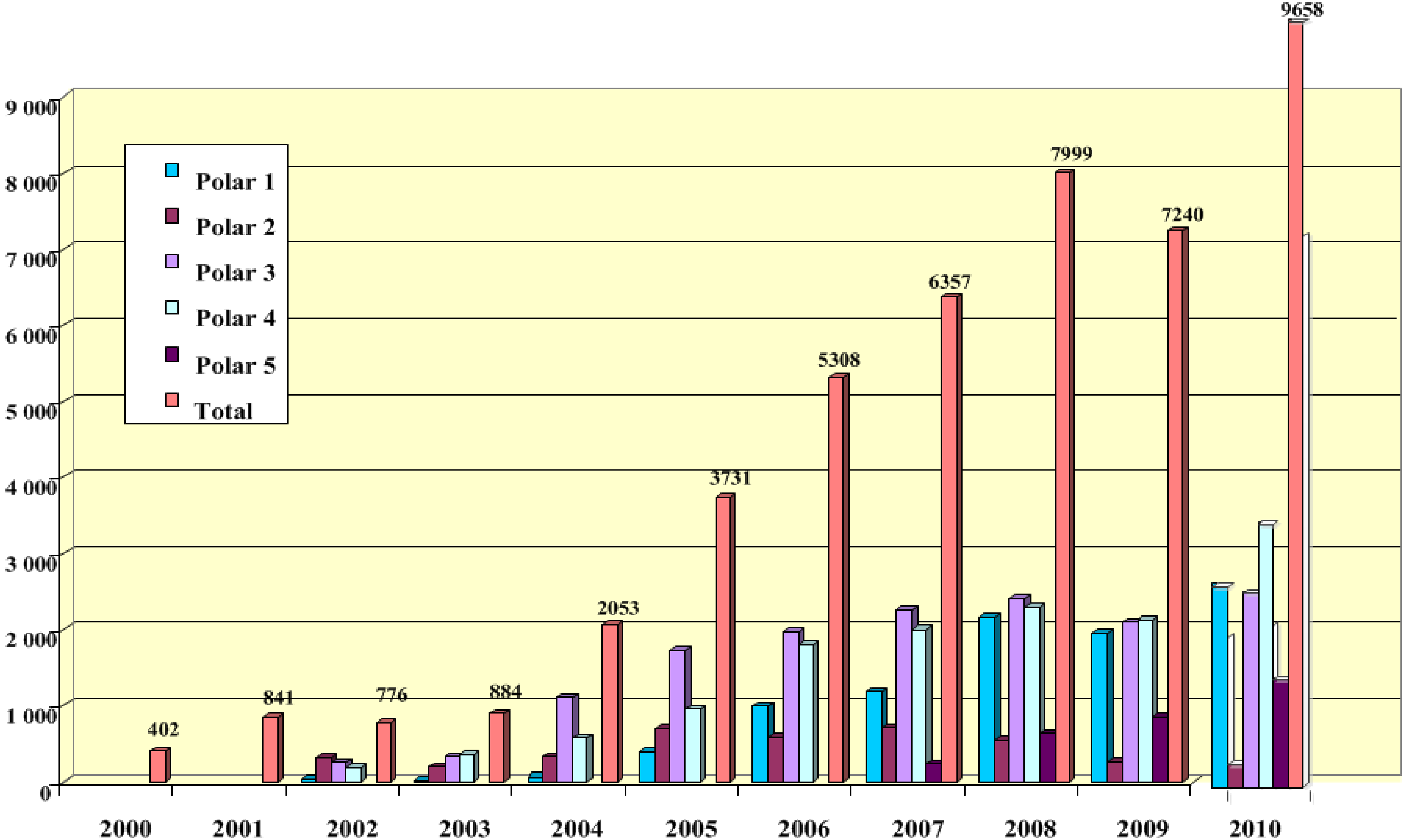
Background – Perspective of Importance

- **International Operators that operate high latitude:**

United Airlines	Singapore Airlines
Delta Airlines	Korean Air Lines
Continental Air Lines	Air China
American Airlines	Emirates Airlines
Cathay Pacific Airways	UPS
Air Canada	China Eastern Airlines
Japan Airlines	Asiana Air Lines
All Nippon Airways	Eva Airways

- **Averaged Annual Number of polar operations for 2010 and 2011: 20,098 (2084 flights/yr increase)**
- **Total # of Flights from 2000-2011: 55,689**

Traffic Density of Polar Routes



Courtesy of Mike Stills of United Airlines

Operational Concept

- **Maximize Use of Polar Airspace by Integrating Space Weather Observation & Forecast Information into decision-making**
  - ➢ Reduce the possibility of degraded Communications capability
  - ➢ Reduce the possibility of Navigation errors
  - ➢ Reduce health risk to Flight Crew and Passengers from exposure to elevated levels of radiation
  - ➢ Improve operational efficiency (reduce long-haul flight cost)

Operational Concept Elements

- **Reduce Impact of Space Weather phenomena on Polar Route operations**
  - Improve "Detect & Forecasts Skills" for operational impact assessments
  - Develop and comply with ICAO guidance and recommendations
    - Lead establishment of Global Observations, Forecast and Dissemination methodology
  - Validate Space Weather Storm Indices
    - Intensity index and frequency of event occurrence
  - Integrate SWx information into global TFM Procedures

Operational Requirements (AUN-2)

- **The Provider State(s) shall observe space weather.**
- **The Provider State(s) shall forecast space weather.**
- **The Provider State(s) shall develop space weather climatologies.**

Derived Requirements from (AUN-2)

- **The Provider State(s) shall observe space weather.**
  - The Provider State(s) shall observe radiation activity.
    - The Provider State(s) shall measure solar proton flux.
    - The Provider State(s) shall measure galactic cosmic rays,
  - The Provider State(s) shall observe geomagnetic activity.
    - The Provider State(s) shall determine the geomagnetic activity level.
    - The Provider State(s) shall measure auroral energy particles

Derived Requirements from (AUN-2)

- **The Provider State(s) shall forecast space weather.**
  - The Provider State(s) shall forecast radiation activity.
    - The Provider State(s) shall forecast solar proton flux.
    - The Provider State(s) shall forecast galactic cosmic rays,
  - The Provider State(s) shall forecast geomagnetic activity.
    - The Provider State(s) shall forecast the geomagnetic activity level.
    - The Provider State(s) shall forecast auroral energy particles

Examples of Performance Requirements

- **Forecast Space Weather**
  - **Forecast Total Electron Content**
    - **The Mid-Term NAS shall forecast the total electron content with an accuracy of plus or minus 25 percent.**
  - **Forecast Solar X-Ray Flux**
    - **The Mid-Term NAS shall forecast the solar x-ray flux in W/m^2 with an accuracy of plus or minus 10 percent.**
  - **Forecast Phase Scintillation Index**
    - **The Mid-Term NAS shall forecast the phase scintillation index with an accuracy of plus or minus 0.1 radians.**

Space Wx Performance Requirements Sub-Team Tasks

- This team will validate space weather functional and performance requirements
  - **Functional Requirements state what must be done**
    - **Observe Space Weather**
    - **Forecast Space Weather**
  - **Performance Requirements state how well it must be done**
    - **Observe Space Weather with an Accuracy of ± X**
    - **Forecast Space Weather with an Accuracy of ± Y**
- To validate the space functional and performance requirements, this team will:
  - **Review draft functional requirements to ensure all needed space weather types are included**
  - **Evaluate the performance values and specify any changes required for needed 2016 capabilities**

Examples of Space Weather Forecast Performance Values

Impact	Element	Latency	Unit/ Resolution	Value Accuracy	Forecast Issue Time					Threshold
					6-hr fcst	12-hr fcst	30-hr fcst	3-day fcst	7-day	
Solar Radiation Activity •Biological Effects •Avionics •High Frequency Radio Propagation •Satellite Navigation	Solar Proton Flux	≤ 10 min	pfu	± 10%	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	10 pfu ≥ 10 MeV (S1)
	Galactic Cosmic Ray Energy Level	≤ 10 min	MeV	5% above median backgrou nd	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	NA
Geomagnetic Activity •High Frequency Radio Propagation •Low Frequency Radio Navigation •Satellite Navigation	Geomagnetic Activity Level	≤ 10 min	Kp index	± 1 Kp index	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	Kp 5 or greater
	Auroral Energy Particle Flux	≤ 10 min	pfu (10 km horiz. res. ≥ 30 deg. N and S)	± 10%	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	N/A
Ionospheric Activity •Satellite Navigation •High Frequency Radio Propagation	Total Electron Content	≤ 10 min	TECU (100 km horizontal resolution)	± 25%	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	N/A
	Amplitude Scintillation Index	≤ 10 min	No unit (25 km spatial resolution)	± 0.1	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	N/A
	Phase Scintillation Index	≤ 10 min	Radians (25 km spatial resolution)	± 0.1	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	N/A
	D-Region Absorption	≤ 10 min	Highest freq. affected in MHz (5° lat. and 15° long. increments)	± 5 MHz	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	daily	N/A
Solar Flares •High Frequency Radio Propagation •Low Frequency Radio Navigation •Satellite Navigation	Solar X-Ray Flux	≤ 10 min	Flux W/m^2	± 10%	every 2 h	every 3 h	00, 06, 12, 18 UTC	daily	Daily	10^{-5} W/m^2 (R1)
Verification	All above	N/A	N/A	N/A	95%	95%	85%	75%	65%	N/A

Concept Development Activities

- **2011: Develop International & NextGen ConOps for Space Wx (SWx)**
  - Operational and Functional Requirements
- **2012: Develop initial Performance Requirements for SWx information**
  - Baseline Requirements (Current Capabilities)
  - Gap Analysis
- **2013: Validate Performance Requirements**
- **2014: Requirements approval at ICAO/WMO Divisional Meeting**
- **2016: Space Wx Standards and Recommended Practices (SARP) for Aviation included in ICAO Annex 3 - Meteorological Service for International Air Navigation**

Work Products

Completed

- **Draft ConOps for International SWx Information in Support of Aviation Operations**
  - **Set of Operational and Functional Requirements for near-term User Needs for ICAO**
  - **Posted on ICAO Website for comment thru June 2012**

    http://www2.icao.int/en/anb/met/iavwopsg/Pages/default.aspx

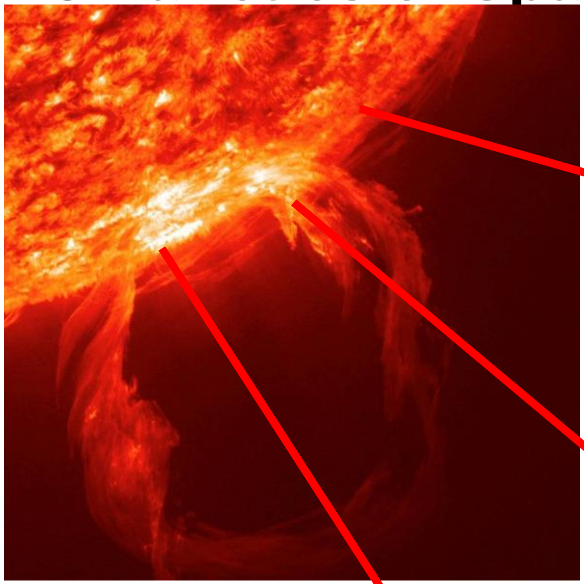
Future

- **SWx Performance Requirements (March 2012)**
- **NextGen SWx Concept of Operations Document for mid and far-term Operational Improvements**
- **Identify Research Activities**

Questions and Additional Slides

Thank you!

3 Varieties of Space Weather: Current Forecast Capabilities



Radio Blackouts

Electromagnetic Radiation

Probabilistic
Poor Accuracy

8-minute transit

Radiation Storms

High Energy Particles

Probabilistic
Fair Accuracy

10-30 minutes transit

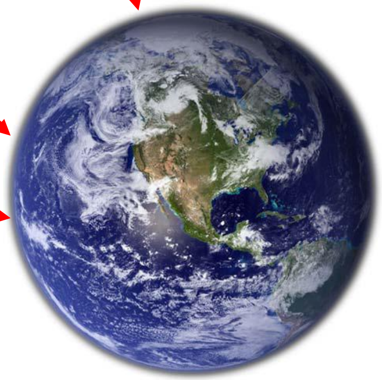
More intense Solar Storms and Blackouts are High Impact/ Low Frequency Events

Geomagnetic Storms

Magnetized Plasma

Deterministic
Good Accuracy

18-96 hours transit



Space Weather Scales

- Three Categories: data they are based on and example users

Geomagnetic Storms

(Ground-based magnetic field)

- Aviation GPS Communication
- Navigation - Avionics Equipment

Solar Radiation Storms

(GOES > 10 MeV particles)

- Aircrew and Passenger Safety
- Airline Communication
- Avionics Equipment

Radio Blackouts

- (GOES Solar X-rays)
- Airline and Maritime HF Comm.

NOAA Space Weather Scales

Category: Scale	Category: Descriptor	Effect Duration of event will influence severity of effects	Physical measure	Average Frequency (1 cycle = 11 years)
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
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)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

Scale	Descriptor	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

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle measurements (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

Scale	Descriptor	Radio Blackouts	GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
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 ($2x10^{-3}$)	Fewer 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 ($5x10^{-5}$)	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)

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

URL: *www.sec.noaa.gov/NOAAScales*

http://swpc.noaa.gov

Concept Traceability

Globally harmonized Space Weather Information for User Needs

- Better science leads to improved information integrated into aviation decision-making

FAA		ICAO
NextGen Concept of Operations	**Enterprise Level Document** (Concept Level 1) ↓	Global Air Traffic Management Operational Concept
Trajectory Based-Operations Concept of Operations	**Service Level Document** (Concept Level 2) ↓	Manual on Air Traffic Management System Requirements
ConOps for International SWx Information in Support of Aviation	**Sub-Service Level Document** (Concept Level 3) ↓	ConOps for NextGen SWx Information in Support of Aviation
Space Weather Information Performance Requirements	**Solution Level Document** (Concept Level 4)	SARP for Space Weather Information

Sample of Reference Documents for this ConOps

- **Space Weather Effects in Regard to International Air Navigation –** Approved ICAO Guidance Material (2011)
- **Aviation Space Weather User Service Needs Manual** (2010)

  "Integrating Space Wx Observations & Forecasts into Aviation Operations"

  - Functional Analysis performed in January 2011 on the set of 20 Aviation User Needs (AUNs) in this Cross-Polar Working Group Document that had reached consensus in December 2010
    - Operational and supporting Functional Requirements were created from completed Functional Analysis (February 2011)
- **The Potential Role of WMO in Space Weather – WMO Space Programme** (2008)
- **AMS Policy Workshop with Recommendations** (2007)
- **SWPC Website: www.swpc.noaa.gov/NOAAScales**
- **SWPC Website: www.swpc.noaa.gov (Alert/Warnings)**

Space Wx Capability Enablers

- **Global Network Satellite System**
  - ➢ US Global Positioning System (GPS)
  - ➢ European Global Positioning Satellite (Galileo)
  - ➢ Russia's Global Positioning Satellite (Glonass)
- **Communication Service Providers**
  - ➢ Ensure proper bandwidth for passing uninterrupted SWx information
- **World Warning Agencies**
  - ➢ Commercial & Government SWx Aviation Information Providers
  - ➢ 13 Global Regional Warning Centers (RWC)
    - ➢ Includes NOAA's Space Weather Prediction Center (SWPC)
  - ➢ International Space Environment Service (ISES)
    - ➢ SWPC is ISES' World Warning Agency
- **Terrestrial Weather Infrastructure:** leverage where appropriate to reduce risks for cost, schedule & technical need

Operational Requirements (AUN-1)

- **The Provider State(s) shall define the impacts of space weather HF communications.**
- **The Provider State(s) shall define the impacts of space weather to VHF communications.**
- **The Provider State(s) shall define the impacts of space weather to UHF communications.**
- **The Provider State(s) shall provide information on the impacts of space weather to satellite communications.**
- **The Provider State(s) shall provide the impacts of radiation on avionics.**
- **The Provider State(s) shall provide the impacts of radiation on humans.**

Impacts from Operational Requirements (AUN-1)

- **Impacts of space weather HF communications - solar extreme ultraviolet (EUV) during flares, solar particle events (SPEs), and geomagnetic storms**
- **Impacts of space weather to VHF communications - solar radio noise.**
- **Impacts of space weather to UHF communications - geomagnetic storms**
- **Impacts of space weather to satellite communications - solar EUV during flares, geomagnetic storms, and SPEs**
- **Impacts of radiation on avionics and humans – galactic cosmic rays (GCR), solar cycle, and SPEs**