International Civil Aviation Organization

SIXTEENTH MEETING OF THE COMMUNICATIONS/NAVIGATION/SURVEILLANCE AND METEOROLOGY SUB-GROUP (CNS/MET SG/16) OF APANPIRG

Bangkok, Thailand, 23 – 27 July 2012

Agenda Item 19: **Any other business**

SPACE WEATHER

(Presented by Australia)

SUMMARY

This paper presents information on Space Weather support for Aviation.
This paper relates to –

Strategic Objectives
A: Safety - *Enhance global civil aviation safety*
C: Environmental Protection and Sustainable Development of Air Transport - *Foster harmonized and economically viable development of international civil aviation that does not unduly harm the environment*

Global Plan Initiatives:
GPI-5 RNAV and RNP (Performance-based navigation)
GPI-7 Dynamic and flexible ATS route management
GPI-9 Situational awareness
GPI-12 Functional integration of ground systems with airborne systems
GPI-15 Match IMC and VMC operating capacity
GPI-16 Decision support systems and alerting systems
GPI-19 Meteorological Systems
GPI-21 Navigation systems
GPI-22 Communication infrastructure

1. Introduction

1.1 The Executive Summary of the draft ‘Concept of Operations (ConOps) for International Space Weather Information in Support of Aviation’[1] provides the following description of space weather:

> *‘Space weather can be defined as the conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can*

[1] ICAO State Letter AN 10/18.2-12/1 ‘Development of operational requirements for space weather.’

endanger human life or health of aviation flight crews and passengers. Unlike terrestrial weather impacts, space weather effects can be global with the onset of their impacts on the earth's atmosphere. The time-scale comparison of impacts on aviation altitudes is also much more rapid following the eruptive episode from either the sun's surface and/or solar outer atmosphere. These events can occur independently or together. The eruptions are the result the nuclear ball of plasma at the core of the sun welling upward and releasing explosively magnetic energy into space in the form of solar flares and Coronal Mass Ejections (CME). Solar flares are the eruptions from the sun's surface and a CME is an eruption of a large volume of the sun's atmosphere – the Corona. These magnetic energy events interact with the Earth's magnetosphere, which allows the highly charged particles from the sun to travel along the magnetic field that converges at the poles and penetrate into lower altitudes – aviation altitudes'

2. Discussion

2.1 Space weather events impact aviation operations by degrading communications, navigation and surveillance (CNS) services and solar radiation can be detrimental to the health of crews and passengers. Communications and navigation satellites could be disabled by significant solar events. More commonly, particularly in the polar regions, space weather conditions can blackout high frequency and satellite communications and satellite navigation services for periods of time from minutes to several hours. There is a threat to human health by exposure to high levels of radiation with the following operational mitigations available: routes based on forecasts of high radiation levels, or in-flight diversions when high radiation levels are observed.

2.2 ICAO through the IAVWOPSG has commenced the development of concept of operations[2] for international space weather information leading to the development of space weather products. A draft of the concept has been circulated to States for comment. States have been invited to comment on the best manner of providing operational space weather products. ICAO is also active through the Navigation Systems Panel and the Asia/Pacific Ionospheric Studies Task Force in assessing space weather effects on GNSS including SBAS and GBAS.

2.3 The availability of applicable weather information plays a key role in any decision-making process, enabling both the operator(s) and traffic flow managers to plan and coordinate a mitigating strategy, rather than react to, impacting weather. This Concept of Operations (ConOps) document for International Space Weather Information identifies and summarizes the progression of the development of space weather support associated with space weather products and services to address communications, navigation, and radiation exposure impacts on aviation operations.

2.4 Airservices Australia, as an air navigation services provider, is particularly interested in the disruptions to communications, navigation and surveillance due to space weather events. Traditionally this has involved high frequency communications prediction services, however with the transition to satellites as core technology, space weather is being considered for deployment for CNS systems.

2.5 The Ionospheric Prediction Service (IPS) is a specialist space weather unit of the Australian Bureau of Meteorology and provides a range of services to the Aviation Industry (see Appendix A for a list of services).

[2] http://www.icao.int/safety/meteorology/iavwopsg/Space%20Weather/Forms/AllItems.aspx

2.6 The observations, analysis, forecasting and distribution of space weather information is currently allocated to MET at the global level, however it is considered that the space weather information function should be more appropriately covered as a multidiscipline approach at the regional level. With respect to APANPIRG, roles are identifiable for ATM in route structure and contingency responses, CNS for the performance of CNS systems and MET for the provision of space weather for operational planning. The meeting is asked to consider the following draft Decision:

Draft Decision 16/x – Space Weather Services

That the CNS/MET SG:

- Note the initiatives from ICAO, States and International Organisations in addressing the global issue of space weather for aviation; and

- Propose a way to engage APANPIRG and its contributory bodies in addressing all aspect of space weather in a regional context.

3. Action by the Meeting

3.1 The meeting is invited to:

a) note the information contained in this paper;

b) discuss any relevant matters as appropriate; and

c) consider the draft Decision regarding Space Weather.

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APPENDIX A – IPS SPACE WEATHER SERVICES FOR AVIATION

A1. Monitoring and alert services based on the NOAA G3, R3 and S3 scales:

The G (geomagnetic storm), R (solar radiation storm), and S (radio blackout) scales are the NOAA space weather scales, see Attachment 1. The G3, R3, and S3 levels are used for issuing alerts to aviation. Examples of space weather effects on Aviation can be found in Attachment 2.

A2. Monitoring and alerts for HF radio fadeouts due to solar Xray flares:

Solar Xray flare events, based on the NOAA R scale, ionise part of the ionosphere causing attenuation (absorption) of HF radiowaves in the sunlit hemisphere (HF fades). The effect on HF radio communication, shown in Figure 1, is modelled based on peak Xray flux. Alerts are issued for HF fades based on solar Xray flux.

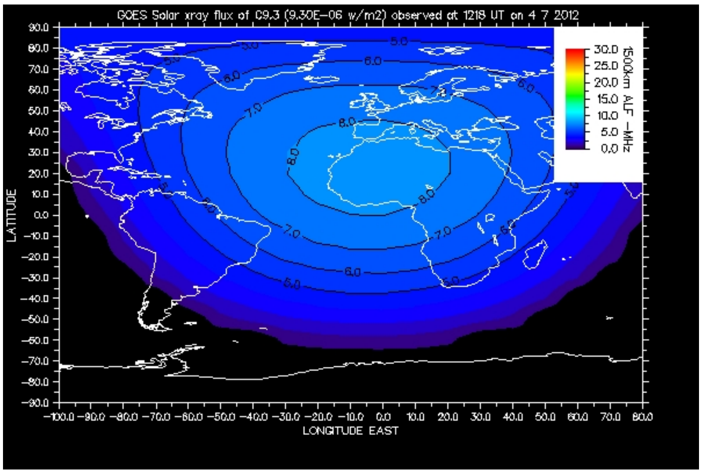


Figure 1 – The effect on HF radio communication caused by solar Xray flare events.

A3. Monitoring and alerts for polar HF blackouts:

Energetic solar proton events (NOAA S scale) result in degraded HF radio propagation throughout the Polar Regions and navigation position errors, and may last for multiple days.

A4. Monitoring and alerts for ground-level events (GeV solar energetic particle events):

Ground-level events are detected by cosmic ray telescopes at high latitudes. Ground-level events occur ~ 16 times per solar cycle. They are an indicator of possible radiation hazard at high latitudes / altitudes due to solar energetic particles.

A5. Forecasting and monitoring of extreme space weather events:

The extreme space weather service is a forecasting and alert service for very high threshold space weather events (NOAA G5, S4/5). This service has been driven by the growing demand for advance warning of extreme space weather events from various critical industries such as aviation. The extreme space weather service is a combination of improved modelling of high threshold events, procedural improvements in the Australian

Space Forecast Centre, and tailored communications for critical industries. The extreme space weather service aims to identify, with reasonable lead-time, solar disturbances with the potential to produce a G5 level storm. Storms at that level occur, on average, ~4 times per solar cycle (11 years), and may produce significant anomalous ionospheric gradients at mid-latitudes. Primarily, the alert service is a forecast with varying lead times from 1-72 hours. There is also a real-time monitoring component to issue immediate alerts on the observation of an ESW event.

A6. Monitoring and alerts for anomalous ionospheric gradients:

The Anomalous Ionospheric Gradient alert service is designed to alert GNSS users of the presence of ionospheric gradients above a critical threshold. The service is based on monitoring GNSS data from short-baseline Continuously Operating Reference Stations networks, from which estimates of peak ionospheric gradient can be calculated. The ionospheric gradient alert service is designed to be near-real time, with a short delay between initial observation, and issuance of an alert, required to eliminate GNSS data artifacts causing false alarms.

A7. HF frequency management for operation of HF radio under disturbed ionospheric conditions:

Hourly and daily HAP (Hourly Area Prediction) charts for HF frequency selection for communication from specific locations, based on current ionospheric conditions, see figure 1. Hourly NAP (Network to Area Prediction) charts for HF communication using multiple base locations and a defined operational area.

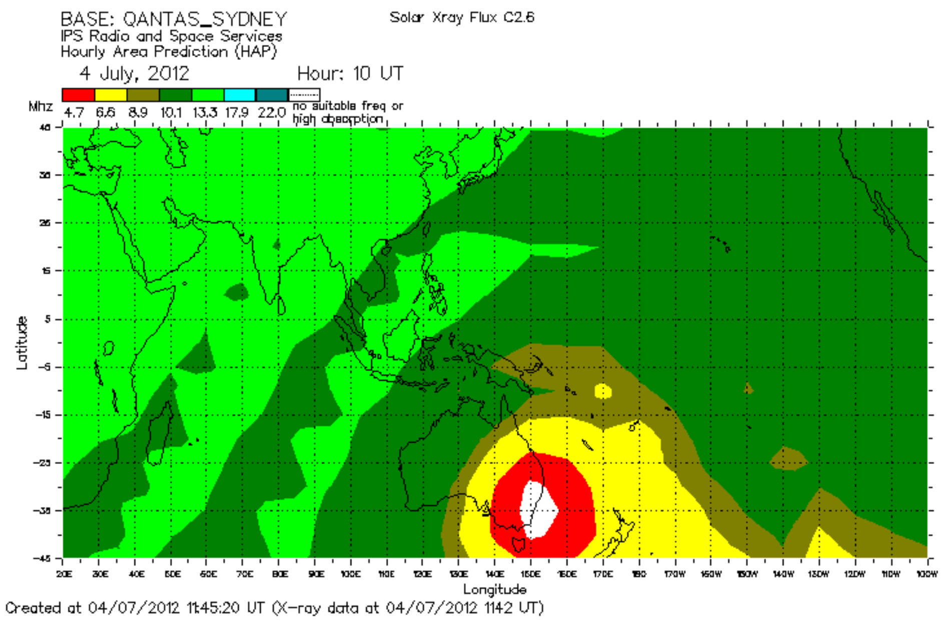


Figure 2 - Hourly HAP (Hourly Area Prediction) chart.

A8. Ionospheric scintillation monitoring:

IPS maintains a network of Ionospheric scintillation monitors in Northern Australia in support of GNSS navigation and Satcom near the equatorial ionospheric anomaly region, and maintains a regional ionospheric delay model driven by real time GNSS data.

ATTACHEMENT 1 – NOAA SPACE WEATHER SCALES

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
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; (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)

Category		Effect	Physical measure	Average Frequency
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); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible. 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; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 10 chest x-rays) is possible. 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 commercial jets at high latitudes may receive low-level radiation exposure (approximately 1 chest x-ray). 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: none. Satellite operations: infrequent single-event upsets possible. Other systems: small 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.

Category		Effect	Physical measure	Average Frequency
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.

ATTACHEMENT 2 – EXAMPLES OF SPACE WEATHER EFFECTS ON AVIATION

Below is a moderate storm from 6-7 March 2012 (extract from presentation by Joe Kunches of the NOAA Space Weather Prediction Centre) to the cross-polar working group.

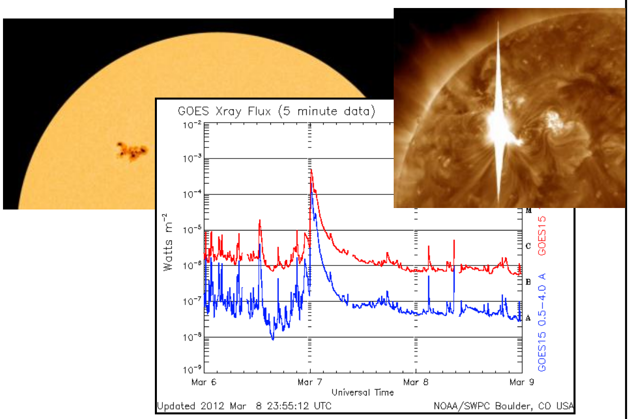
Full presentation available from the FAA at:
http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/oceanic/documents/cross_polar/CPWG13/Space_Weather_2012_jmk.ppt

First R3/S3/G3 Space Weather Storm of the Solar Cycle

Solar Flare Radio Blackout Forecast

Forecast for Mar 6-7, 2012
Issued: Mar 5, 22:00 UTC
R1 (Minor) – R2 (Moderate): **75%**
R3 (Strong): **30%**

Actual: R3 Flare – Mar 7, 00:24 UT

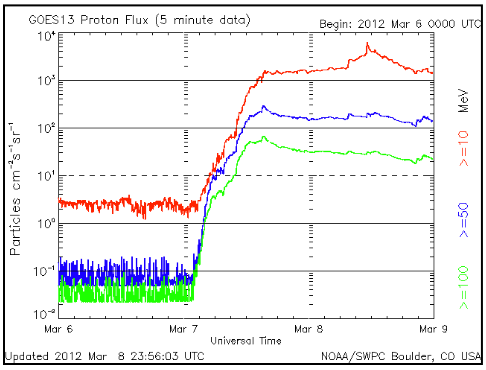


Radiation Storm Forecast

Radiation Storm Warning issued at Mar 7, 00:19 UTC

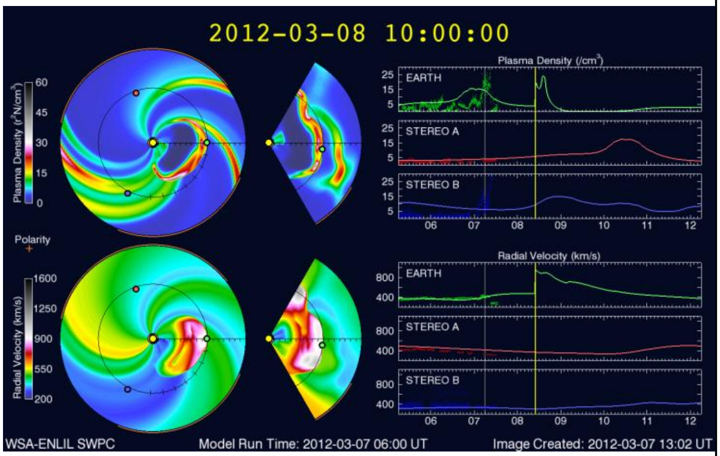
Actual: Onset – Mar 7, 05:10 UT

Almost five hours warning (lead) time.



Geomagnetic Storm Forecast, March 7, 2012

- WSA/Enlil model indicated Mar 8, 10UTC arrival at Earth.
- A "G3 Watch" was issued Mar 7 at 17:42UTC…17 hours before the storm onset.
- Stronger storming was expected on Mar 8, but solar wind not suitable for stronger storming until Mar 9.

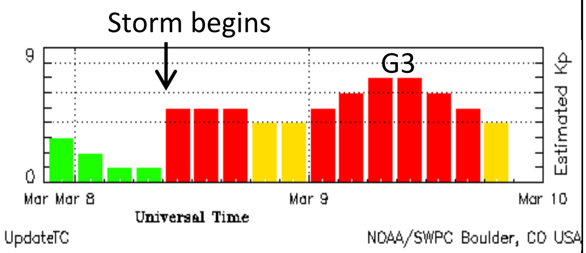


Geomagnetic Storm Forecast:

"The arrival time is estimated to be Mar 8 at 06:00-10:00UTC."

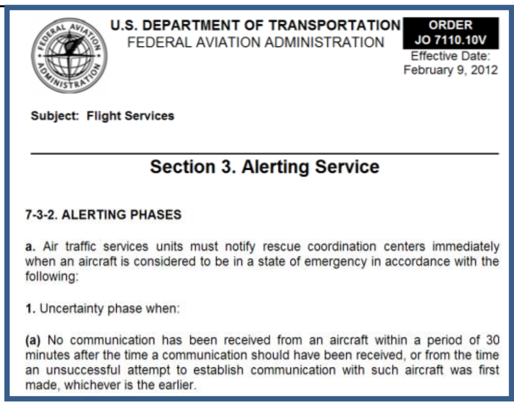
"Periods reaching the G3 (Strong) Level Likely"

Actual: Arrival: Mar 8, 11:05UTC



March 2012
Impacts on Aviation

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

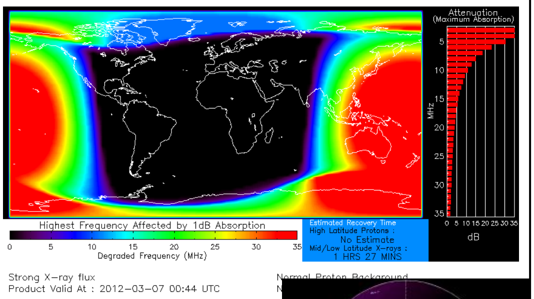
a. Air traffic services units must notify rescue coordination centers immediately when an aircraft is considered to be in a state of emergency in accordance with the following:

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



- Several polar flights altered.
- Numerous reports of HF communication outages on lower-latitude trans-oceanic flights.
- FAA WAAS reported the detection of minor issues for GPS users in Alaska.