International Civil Aviation Organization

INFORMATION PAPER

Twenty-third Meeting of the Meteorology Sub-group (MET SG/23) of the Asia and Pacific Air Navigation Planning and Implementation Regional Group (APANPIRG)

Bangkok, Thailand, 17 – 20 June 2019

Agenda Item 3: Planning and monitoring related to implementation of meteorological service

INTRODUCTION OF SPACE WEATHER ADVISORIES

(Presented by Australia)

SUMMARY

This paper provides an overview of the space weather advisory service to, focusing on the Australian Bureau of Meteorology's roles and preparations toward delivering this new service to aviation.

1. INTRODUCTION

1.1 ICAO Annex 3 *Meteorological Service for International Air Navigation* Amendment 78 (effective November 2018) identified Contracting States the responsibility for providing Space Weather Advisories. Annex 3 recommends that Space Weather Advisories shall be issued in abbreviated plain language. Furthermore, from 7 November 2019 Space Weather Advisories are also recommended to be disseminated in IWXXM GML form. As of 5 November 2020, in addition to abbreviated plain language, dissemination of space weather advisory information in IWXXM GML form will become a standard.

1.2 The introduction of Standards and Recommended Practices (SARPs) for a space weather information service will be supported by the *Manual on Space Weather Information in Support of International Air Navigation* (Doc 10100) which is currently being developed.

1.3 The 215th session of the ICAO Council agreed on the designation of the three global Space Weather Centres (the ACJF (Australia, Canada, France and Japan) consortium, the European PECASUS consortium, and the United States), with two Regional Centres, (China/Russian Federation consortium and South Africa), to be established no later than November 2022.

2. DISCUSSION

Operational Overview of Space Weather Centres (SWXCs)

2.1 The ICAO Meteorological Panel (METP) Working Group on Meteorological Information and Service Development (WG-MISD) has been tasked with designing a globally consistent service consisting of the aforementioned Space Weather Centres (SWXCs).

2.2 The proposal within WG-MISD is for each of the three global centres to operate for a two-week period, every six weeks and, when not operating as the active (duty) centre, they will operate as a primary backup centre or secondary backup centre for 2 weeks each respectively.

2.3 It should also be noted that the ACJF Consortium will issue advisories from 2 centres, these being Melbourne Australia (YMMC) and Toulouse France (LFPW). HF Advisories will be issued by Melbourne and other SWX advisories from Toulouse.

2.4 It is also proposed that SWX administrative messages will be issued to inform users of each occurrence of rotation of responsibilities (who is the new on-duty centre) and to support testing of the dissemination system.

2.5 Implementation planning is underway and the operations is expected to commence on 7 November 2019 (AIRAC date).

Types of Space Weather Effects

2.6 The space weather advisories for aviation will consist of four types of space weather effects (SWXs), namely Global Navigation Satellite Systems (GNSS), High-Frequency Radio Communications (HF COM), Radiation and Satellite Communications (SATCOM). Some of SWXs are further subdivided into sub-effects. These, together with the parameters and threshold used to qualify these SWXs are as follows:

Effect	Sub-effect	Parameter used	Moderate	Severe
GNSS	Amplitude Scintillation	S4 (dimensionless)	0.5	0.8
GNSS	Phase Scintillation	Sigma-phi (radians)	0.4	0.7
GNSS	Vertical Total Electron Content (TEC)	TEC units	125	175
RADIATION		Effective dose (micro-Sieverts/hour)	30	80
HF COM	Auroral Absorption (AA)	Kp	8	9

HF COM	Polar Cap Absorption (PCA)	dB from 30MHz riometer data	2	5
HF COM	Shortwave Fadeout (SWF)	Solar X-rays (0.0-0.8 nm) ($W\text{-}m^{-2}$)	$1x10^{-4}$ (X1)	$1x10^{-3}$ (X10)
HF COM	Post-Storm Depression	MUF	30%	50%
SATCOM	No threshold has been set for this effect			

2.7 A space weather advisory will be issued when the aforementioned moderate and/or severe threshold has been exceeded. Simultaneous occurrence of space advisories of same sub-effect would be combined into one advisory. The spatial extent of the SWX is either described using six pre-defined latitude bands of width 30°, followed by a longitude range in 15° increments or using a four-side polygon.

2.8 Subsequent updates will be issued every 6 hours if the affected region and severity level remains unchanged. Updates can be issued at an earlier time, if there is a significant change in the affected region, severity level and/or if the SWX event has ended.

Space Weather Advisories and Dissemination

2.9 The ICAO SARPs for space weather defined through Amendment 78 of Annex 3 specifies the advisory types, issuance criteria, format, sequencing and all other details related to space weather advisories. The associated Manual on Space Weather Information in Support of International Air Navigation, 1st Ed (2018) specifies the alerting thresholds and describes in more detail the potential impact on operations from an aviation users perspective.

2.10 It is proposed that the Space Weather Advisories (SWXA) will be disseminated to users similarly to METAR/SPECI and TAFs and differently to other advisories. Moreover, SWXA will be distributed via the ROBEX distribution mechanisms rather than directly to end users via AFTN/AMHS.

2.11 Specifically, Space Weather Centres (SWXCs) will send advisories to their National OPMET Centre (NOC), who will onforward the message to their Regional OPMET Centre (ROC), who will onforward the message to the Inter-regional OPMET Gateway (IROGs) and other regional ROCs (who will make available to National Operation Centres (NOCs) within their area of responsibility). The IROGs will distribute the message to their neighbouring IROGs and internet-based services (SADIS and WIFS).

2.12 Users will access Space Weather Advisories through their normal national aviation briefing service but it should be noted that airlines may request their NOCs to deliver SWXAs directly to the airline, via AFTN/AMHS, like other OPMET information.

2.13 Melbourne Australia (YMMC), whose primary responsibility is HF COM advisories, will generate space weather advisories at the Australian Bureau of Meteorology (BOM) Space Weather Service (SWS) and will disseminate them through the NOC of BOM. Both NOC and SWS maintain a 24-hour, 365-day support for their systems.

Forecaster Training and User Education

2.14 Forecasters from SWS and NOC of the BOM are been trained to provide expert support and disseminate the space weather advisories, respectively. The training program involved a few real-time scenarios, providing forecasters with an exposure to significant space weather events from the past.

2.15 BoM in coordination with the ACFJ partner, Meteo-France, has successfully completed end-to-end testing via AFTN between Melbourne Australia (YMMC) and Toulouse France (LFPW). Furthermore, end-to-end testing of the space weather advisories will be conducted with other global centres in preparation for the implementation phase.

2.16 To support the seamless delivery of a space weather advisory service within the ACJF Consortium, an internal website is been developed by BOM which contains information on any active or recently issued space advisory, as well as current/forecasted space conditions.

2.17 These advisories, together with the relevant graphics will be made available to our customers using the BOM Aviation Weather page (http://www.bom.gov.au/aviation/).

2.18 To educate the Australian aviation industry on the hazards of space weather, and the format and content of the Space Weather Advisories, two information brochures, have been published.

2.19 The first brochure (Attachment 1) "Hazardous Weather Phenomena – Space Weather" describes space weather and its hazards and impacts on the aviation industry. The purpose of this brochure is to assist users in understanding the hazards of space weather.

2.20 The second brochure (Attachment 2) "Aviation Weather Products – Space Weather Advisories" gives detailed information on the format and content of the Space Weather Advisories. The purpose of this brochure is to help users understand and interpret Space Weather Advisories.

2.21 Both brochures are available on the BOM Aviation Weather Services, Knowledge Centre web page http://www.bom.gov.au/aviation/knowledge-centre/ .

3. ACTION BY THE MEETING

3.1 Note the information contained in this paper.

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HAZARDOUS WEATHER PHENOMENA
Space Weather

Bureau of Meteorology › Aviation Meteorological Services

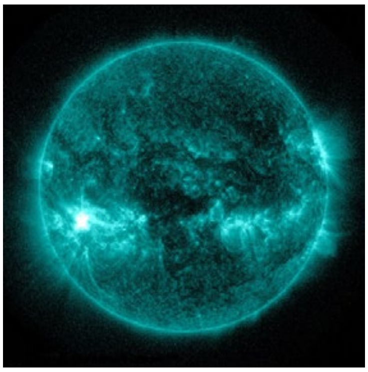

Photo credit: NASA/GSFC/Solar Dynamics Observatory

Space weather events may cause disruptions to aviation communications, navigation and surveillance systems, and increase radiation exposure at cruising levels.

The aurora is the visible manifestation of space weather in the polar regions. Photo credit: NASA

What is Space Weather?

Space Weather broadly describes the impact of solar activity on technological systems and human well-being here on earth. Dynamic variations on the surface of the sun can release large amounts of energy in various forms including electromagnetic radiation, charged particles and eruptions of huge clouds of ionised gas. These phenomena can significantly affect the earth's upper atmosphere and surrounding space environment with impacts felt all the way down to technological systems on the ground.

Particularly concerning for communications and navigation systems, solar variations both directly and indirectly modify a layer of the earth's upper atmosphere known as the ionosphere. The ionosphere extends upwards from 90 km above the earth's surface.

High-frequency (HF) radio communication relies on the ionosphere reflecting radio-waves back down to the ground. Long range voice and data communication, including the range of usable HF frequencies, can vary according to the state of the ionosphere.

Satellite communication (SATCOM) and satellite-based navigation and surveillance (SATNAV) that use Global Navigation Satellite Systems (GNSS) (e.g. GPS), rely on the transmission of signals through the ionospheric layer. These signals are modified in various undesirable ways as they travel through the ionosphere, depending on its density and structure.

Space weather events that modify the density and/or structure of the ionosphere can therefore significantly impact the performance of HF communications, SATCOM and SATNAV systems.

Apart from effects associated with the ionospheric layer, the release of highly energetic particles from the sun during solar disturbances can result in increased, potentially dangerous, radiation at cruising levels. Radiation exposure increases with altitude and with closer proximity to the poles.

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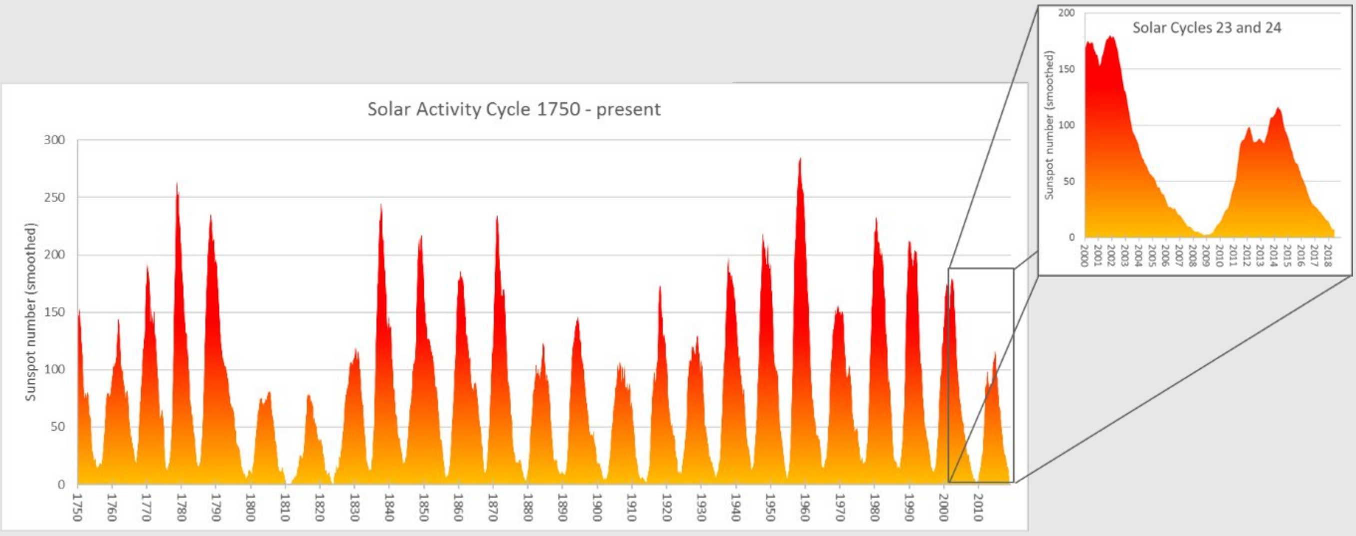
Solar Activity Cycle

The level of solar activity varies over an 11-year cycle. While space weather events impacting aviation can occur at any time during a solar cycle, they are most common and generally more intense around the peak of the cycle (sunspot number at its highest). A single solar eruption can trigger a series of space weather events with effects lasting over a period of 1–3 days. Impacts often occur in bursts, separated by prolonged periods of no significant activity..



The 11-year solar activity cycle illustrated by sunspot number over the last 250 years. The inset shows the last two cycles. Solar minimum will occur during 2019. The sunspot number is an index of solar activity based on counting sunspots and sunspot groups. Sunspots have been observed since the time of Galileo. Image credit: Bureau of Meteorology

Space Weather Impacts on Aviation

High-Frequency (HF) Radio Communications

Radiation produced by the sun in the extreme ultraviolet (EUV) and X-ray frequency range is typically absorbed in the ionosphere at altitudes above 90 km. This region of charged particles supports HF radio communications by reflecting HF radio waves back down towards the ground, enabling long distance communications. Emissions associated with solar flares and high-energy solar protons can also ionise the earth's atmosphere at lower altitudes, causing increased absorption of HF radio waves and reducing the range of usable HF frequencies.

Photo credit: Jessica Neaves

These 'absorption events' usually impact just the *lower* HF radio frequencies. Very strong solar X-ray flares however, can result in HF radio blackout conditions (affecting all frequencies) that can persist for minutes to hours on the sunlit side of the earth. Bursts of high-energy protons emitted by the sun (solar proton events) can impact the polar regions, producing radio blackout conditions that can last from hours to days. Similarly auroral absorption (AA) events occur in the auroral oval regions surrounding the poles and can persist for minutes to hours. During these events, radio operators are advised to try higher frequencies, or use an alternate means of communication.

In addition to absorption events, geomagnetic storms can reduce the density of electrons in the ionosphere, again resulting in a reduced range of frequencies available for HF communications. These 'ionospheric depression' events usually impact just the *higher* HF radio frequencies and can persist from hours to days. During these events, radio operators are advised to try lower HF frequencies

GNSS-based Navigation and Surveillance

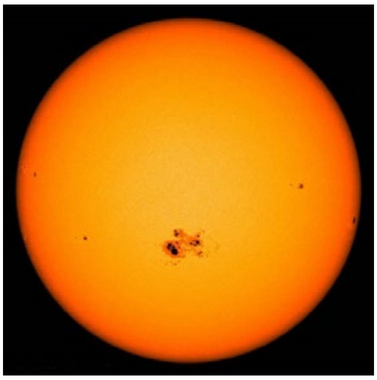
One of the largest sources of error in Positioning Navigation and Timing (PNT) signals from GNSS satellites is due to the passage of the satellite signal through the relatively dense electron environment of the upper atmosphere. These errors are

On August 31, 2012 a long filament of solar material that had been hovering in the sun's atmosphere, the corona, erupted out into space at 4:36 p.m. EDT. The coronal mass ejection, or CME, travelled at over 900 miles per second. The CME did not travel directly toward earth, but did connect with earth's magnetic environment, or magnetosphere, causing aurora to appear on the night of Monday, September 3. Pictured here is a lighten blended version of the 304 and 171 angstrom wavelengths. Photo credit: NASA/GSFC/SDO NASA Goddard Space Flight Centre

compensated for by GPS receivers that use an ionospheric delay correction model. During ionospheric storms, or periods where the ionosphere deviates significantly from normal conditions, these models may be inadequate and lead to uncorrected positioning errors. Precision navigation systems that autocorrect for the ionosphere, such as differential GPS, or GPS augmentation systems such as the Satellite-Based Augmentation System (SBAS) or Ground-Based Augmentation System (GBAS) are still susceptible to errors during severe ionospheric storms. GNSS positioning is also susceptible to interference from solar radio bursts in the ultra-high-frequency (UHF) range, leading to significant loss of satellite tracking for up to tens of minutes in severe cases.

Ionospheric scintillation is the rapid fluctuation of the power and/or phase of radio signals passing through the ionosphere. Scintillation occurs when a radio frequency signal, up to a few gigahertz (GHz), passes through a region of small-scale irregularities in the ionospheric electron density. The effect can be compared to the twinkling of stars as their light passes through the earth's atmosphere.

Scintillation occurs primarily in the equatorial region of the earth (+/- 20° latitude) between dusk and midnight. This is due to large electron density depletions known as Equatorial Plasma Bubbles in the ionosphere above those areas. Scintillation can also occur in high-latitude regions. Scintillation effects are most significant in L-band SATCOM and SATNAV applications where GHz-frequency signals travel through the ionosphere. For SATNAV, the rapid signal fluctuations impede the ability of GNSS receivers to track signals from individual GNSS satellites. This results in fewer satellites available for positioning and reduces positioning accuracy. In the worst-case scenario, scintillation can result in a complete loss of GNSS positioning for up to tens of minutes. For SATCOM, scintillation can result in reduced signal-to-noise ratio and poor communication quality.



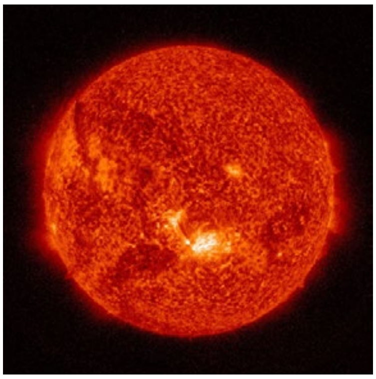


Photo credit: NASA/GSFC/Solar Dynamics Observatory

Radiation

During solar eruptive events, large numbers of energetic particles may be released from the sun and travel to earth. The particles travel along earth's magnetic field lines, collide with air molecules and produce showers of secondary particles in the atmosphere. These particles are ultimately stopped by the relatively dense lower atmosphere of the earth. In the equatorial and mid-latitude regions, the earth's near-horizontal magnetic field acts as a shield. In the polar regions however, where the magnetic field is closer to vertical, the energetic particles can cascade down to lower altitudes or even reach the ground, increasing radiation exposure for people in the vicinity. As these particles are weakened (slowed and absorbed) by passage through the atmosphere, higher altitudes are exposed to higher levels of radiation. The radiation exposure of flight crew and passengers can significantly increase during these solar energetic particle events, particularly on polar or near-polar flights.

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Airservices Australia is the official distributor of aviation forecasts, warnings and observations issued by the Bureau of Meteorology. Airservices' flight briefing services are available at www.airservicesaustralia.com. Telephone contact details for elaborative briefings are contained in Airservices' Aeronautical Information Publication Australia (AIP), which is available online through their website.

Other brochures produced by the Bureau of Meteorology's aviation weather services program can be found at www.bom.gov.au/aviation/knowledge-centre.

AVIATION WEATHER PRODUCTS
Space Weather Advisories

Bureau of Meteorology › Aviation Meteorological Services

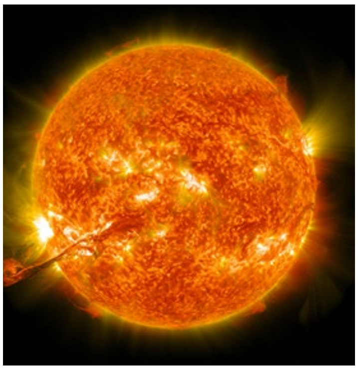


Photo credit: NASA/GSFC/Solar Dynamics Observatory

The Bureau of Meteorology is one of the ICAO designated Space Weather Advisory Centres responsible for monitoring and providing advisory information on space weather phenomena to the aviation industry.

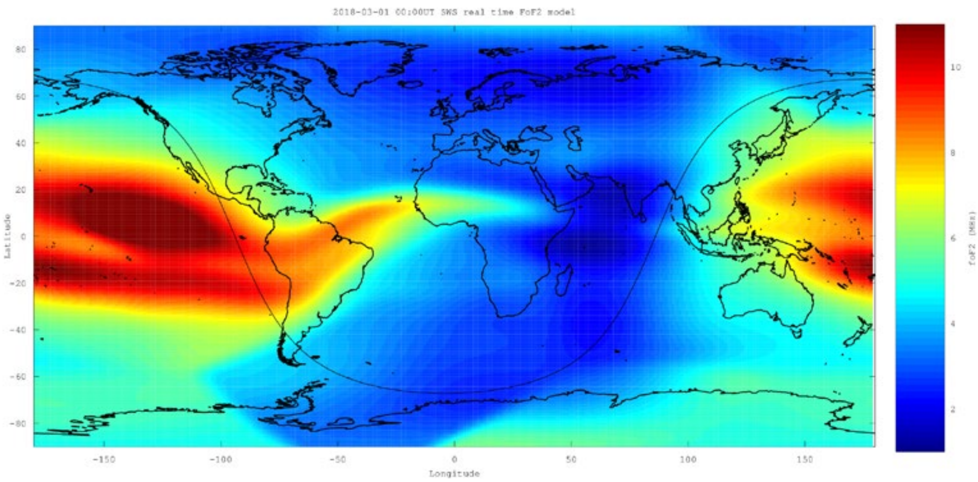
The aurora is the visible manifestation of space weather in the Polar Regions.
Photo credit: NASA

Australian Government
Bureau of Meteorology

Space Weather Advisories

Space weather can be described as the solar activity on the surface of the sun creating certain atmospheric events that can affect us here on earth. These environmental conditions are important for us to monitor as they can affect the performance and reliability of our satellites, navigation systems and radio communications. Those flying at high altitudes are also at risk of increased radiation exposure.

The effects of space weather events can last anywhere from a few seconds to a number of days. Space weather forecasts for international air navigation address particular types of disturbances such as solar radiation storms, geomagnetic storms, ionospheric storms and solar flares. These forecasts enable operators to maintain awareness of potential hazards and to formulate alternative plans should the impending conditions be of a magnitude and/or type that could disrupt normal operations.



Global map of maximum useable frequency for HF Radio users.
Photo credit: Bureau of Meteorology

Space Weather Definitions

Code	Definition
SWX	Space Weather
SWXC	Space Weather Centre
HF COM	High frequency communications (propagation, absorption)
SATCOM	Communications via satellite (propagation, absorption)
GNSS	Global navigation satellite system-based navigation and surveillance (degradation)
RADIATION	Radiation at flight levels (increased exposure)
HNH	High latitudes northern hemisphere
MNH	Middle latitudes northern hemisphere
EQN	Equatorial latitudes northern hemisphere
EQS	Equatorial latitudes southern hemisphere
MSH	Middle latitudes southern hemisphere
HSH	High latitudes southern hemisphere

Spatial Ranges and Resolution

Element to be forecast		Range	Resolution
Flight level affected by radiation		FL250 – FL600	30
Longitudes for advisories (degrees)		000° –180° (E&W)	15
Latitudes for advisories (degrees)		00° – 90° (N&S)	10
Latitude bands for advisories (degrees and minutes)	High latitudes northern hemisphere (HNH)	N9000 – N6000	30
	Middle latitudes northern hemisphere (MNH)	N6000 – N3000	
	Equitorial latitudes northern hemisphere (EQN)	N3000 – N0000	
	Equitorial latitudes sourthern hemisphere (EQS)	S0000 – S3000	
	Middle latitudes sourthern hemisphere (MSH)	S3000 – S6000	
	High latitudes sourthern hemisphere (HSH)	S6000 – S9000	

Message Structure

WMO header
The World Meteorological Organization header is included to facilitate the international exchange of messages.

Message type
The message type is identified as SWX (space weather) ADVISORY.

SWX ADVISORY

Status indicator
Idicator of test or exercise.

TEST or EXER

Time of origin
Year, month, day and time of issue followed by the letter Z (universal time coordinated, UTC).

DTG: 20161108/0100Z

Name of SWXC
The name of the Space Weather Centre.

SWXC: DONLON*

Advisory number
Year in full and unique message number.

ADVISORY NR: 2016/2

Number of advisory being replaced
Number of the previously issued being replaced.

NR RPLC: 2016/1

Space weather effect & intensity
Effect and intensity of the space weather phenomena.

SWX EFFECT: GNSS MOD

Observed or expected space weather phenomena
Day and time (UTC) of observed phenomena (or forecast if phenomena have yet to occur).

Horizontal extent (latitude bands and longitude in degrees) and/or altitude of space weather phenomena.

OBS SWX: 08/0100Z HNH HSH E18000 – W18000

Forecast of the phenomena (+6 HR)
Day and time (UTC) (6 hours from the time given in Item 8, rounded to the next full hour).

Forecast extent *and/or* altitude of the space weather phenomena for the validity period.

FCST SWX +6 HR: 08/0700Z HNH HSH E18000 – W18000

Forecast of the phenomena (+12 HR)
Day and time (UTC) (12 hours from the time given in Item 8, rounded to the next full hour).

Forecast extent *and/or* altitude of the space weather phenomena for the validity period.

FCST SWX +12 HR: 08/1300Z HNH HSH E18000 – W18000

Forecast of the phenomena (+18 HR)
Day and time (UTC) (18 hours from the time given in Item 8, rounded to the next full hour).

Forecast extent *and/or* altitude of the space weather phenomena for the validity period.

FCST SWX +18 HR: 08/1900Z HNH HSH E18000 – W18000

Forecast of the phenomena (+24HR)
Day and time (UTC) (24 hours from the time given in Item 8, rounded to the next full hour).

Forecast extent *and/or* altitude of the space weather phenomena for the validity period.

FCST SWX +24 HR: 09/0100Z NO SWX EXP

Remarks
Remarks, as necessary.

RMK: LOW LVL GEOMAGNETIC STORMING CAUSING INCREASED AURORAL ACT AND SUBSEQUENT MOD DEGRADATION OF GNSS AVBL IN THE AURORAL ZONE. THIS STORMING EXP TO SUBSIDE IN THE FCST PERIOD. SEE WWW.SPACEWEATHERPROVIDER.WEB

Next advisory
Year, month, day and time in UTC.

NXT ADVISORY: NO FURTHER ADVISORIES

Examples

Space weather advisory message (GNSS effects)

SWX ADVISORY
DTG: 20161108/0100Z
SWXC: DONLON*
ADVISORY NR: 2016/2
NR RPLC: 2016/1
SWX EFFECT: GNSS MOD
OBS SWX: 08/0100Z HNH HSH E18000 – W18000
FCST SWX +6 HR: 08/0700Z HNH HSH E18000 – W18000
FCST SWX +12 HR: 08/1300Z HNH HSH E18000 – W18000
FCST SWX +18 HR: 08/1900Z HNH HSH E18000 – W18000
FCST SWX +24 HR: 09/0100Z NO SWX EXP
RMK: LOW LVL GEOMAGNETIC STORMING CAUSING INCREASED AURORAL ACT AND SUBSEQUENT MOD DEGRADATION OF GNSS AVBL IN THE AURORAL ZONE. THIS STORMING EXP TO SUBSIDE IN THE FCST PERIOD. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY: NO FURTHER ADVISORIES

Space weather advisory message (RADIATION effects)

SWX ADVISORY
DTG: 20161108/0000Z
SWXC: DONLON*
ADVISORY NR: 2016/2
NR RPLC: 2016/1
SWX EFFECT: RADIATION MOD
FCST SWX: 08/0100Z HNH HSH E18000 – W18000 ABV FL 350
FCST SWX +6 HR: 08/0700Z HNH HSH E18000 – W18000 ABV FL 350
FCST SWX +12 HR: 08/1300Z HNH HSH E18000 – W18000 ABV FL 350
FCST SWX +18 HR: 08/1900Z HNH HSH E18000 – W18000 ABV FL 350
FCST SWX +24 HR: 09/0100Z NO SWX EXP
RMK: RADIATION LVL EXCEEDED 100 PCT OF BACKGROUND LVL AT FL350 AND ABV. THE CURRENT EVENT HAS PEAKED AND LVL SLW RTN TO BACKGROUND LVL. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY: NO FURTHER ADVISORIES

Space weather advisory message (HF COM effects)

SWX ADVISORY
DTG: 20161108/0100Z
SWXC: DONLON*
ADVISORY NR: 2016/1
SWX EFFECT: HF COM SEV
OBS SWX: 08/0100Z DAYLIGHT SIDE
FCST SWX +6 HR: 08/0700Z DAYLIGHT SIDE
FCST SWX +12 HR: 08/1300Z DAYLIGHT SIDE
FCST SWX +18 HR: 08/1900Z DAYLIGHT SIDE
FCST SWX +24 HR: 09/0100Z NO SWX EXP
RMK: PERIODIC HF COM ABSORPTION AND LIKELY TO CONT IN THE NEAR TERM. CMPL AND PERIODIC LOSS OF HF ON THE SUNLIT SIDE OF THE EARTH EXP. CONT HF COM DEGRADATION LIKELY OVER THE NXT 7 DAYS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:20161108/0700Z

*DONLON is a fictitious Space Weather Centre

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Airservices Australia is the official distributor of aviation forecasts, warnings and observations issued by the Bureau of Meteorology. Airservices' flight briefing services are available at www.airservicesaustralia.com. Telephone contact details for elaborative briefings are contained in Airservices' Aeronautical Information Publication Australia (AIP), which is available online through their website.

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