

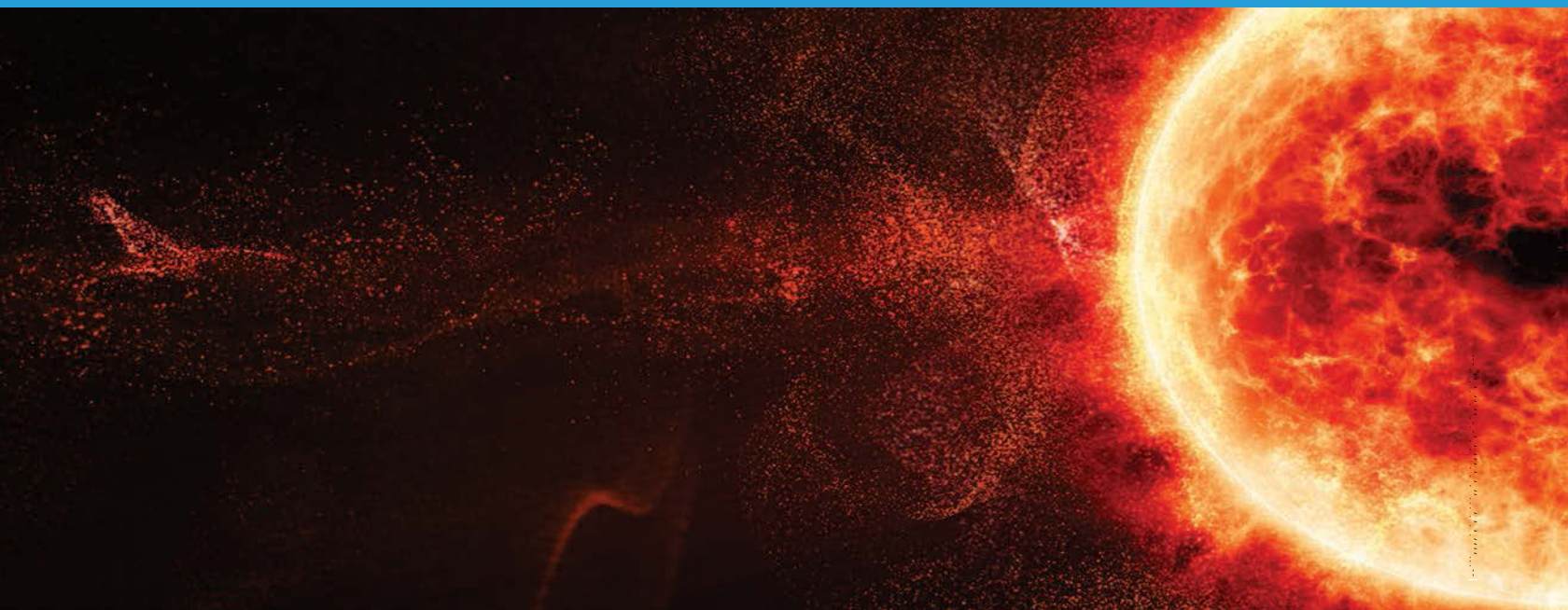


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Doc 10100

Manual on Space Weather Information in Support of International Air Navigation

First Edition, 2019



Approved by and published under the authority of the Secretary General

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

This first edition of the *Manual on Space Weather in Support of International Air Navigation* (Doc 10100) is published in response to the introduction of provisions related to the dissemination of information on space weather to international air navigation as part of Amendment 78 to Annex 3 — *Meteorological Service for International Air Navigation*. As of this date, designated space weather centres (SWXC) will monitor and provide advisory information on space weather phenomena expected to affect high-frequency radio communications, communications via satellite, GNSS-based navigation and surveillance systems and/or pose a radiation risk to aircraft occupants. Annex 3 requires that SWXC maintain a 24-hour watch and, after the issuance of the advisory information, supply this information to area control centres, flight information centres and aerodrome meteorological offices which may be affected; as well as other SWXC, international OPMET databanks, international NOTAM offices and aeronautical fixed service Internet-based services.

This manual aims to provide guidance for aeronautical meteorologists, particularly those at the operational level, as well as for operators, flight crew members, air traffic services units, search and rescue services units, airport management and others concerned with the conduct or development of international air navigation. It describes practices to be applied in the provision, reception and use of information on space weather phenomena affecting international air navigation. Chapter 1, the introduction, contains information on the space weather phenomena themselves, the hazards and mitigation aspects. Chapter 2 deals with space weather and aviation operations; it provides information on the different types of eruptive space weather disturbances which may have a direct impact on critical systems used in aviation. Chapter 3 addresses primarily the information required for safe and efficient aircraft operations provided to users for their decision-making processes. Chapter 4 provides guidance on the use of space weather advisory information which, in some events, may occur suddenly and need a fast response by flight crews and ANSPs due to the insidious impacts of space weather events on systems and associated high radiation levels. Finally, Appendices A and B contain categories of space weather phenomena and background information about the phenomena.

The content of the manual was developed with the assistance of the ICAO Meteorology Panel (METP) and its specific group on space weather composed of experts from a number of States, user organizations and the World Meteorological Organization (WMO). It is hoped that this manual will be useful in supporting the implementation of the provision and use of space weather information, thus contributing to the safe and sustainable operation of international air navigation.

Comments concerning this manual should be addressed to:

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GLOSSARY

DEFINITIONS

When the following terms are used in this manual, they have the following meanings:

Effective dose. A quantity defined by the ICRP that accounts for the type of incoming radiation as well as the nature of the material or organ being irradiated.

Ionosphere. The region of the Earth's upper atmosphere containing free electrons and ions, extending from about 60 to 1 000 km above Earth's surface.

Magnetic latitude. A coordinate system linked to the location of the magnetic poles rather than the geographic poles. It is most relevant for space weather effects as charged particles are modulated by magnetic fields and are insensitive to geographic locations.

Magnetosphere. The volume of space near the Earth, influenced by the interaction between Earth's magnetic field and the solar wind.

Scintillations. In the context of this manual, scintillations refer to the variations in amplitude and phase of a GNSS signal located in L-band (1-2 GHz) of the radio spectrum, due to effects from diffraction and refraction.

Solar maximum. A few year period, centered around the point of the 11-year solar cycle, during which solar eruptive activity is at its peak.

Thermosphere. The region of the Earth's upper atmosphere with air density so low that it is commonly referred to as outer space. It extends from roughly 90 to between 500 and 1 000 km.

ACRONYMS

ABV	above ADS-A
ADS-B	automatic dependent surveillance — broadcast
ADS-C	automatic dependent surveillance — contract
ATFM	air traffic flow management
AIS	aeronautical information service
ANP	actual navigation performance
ANSP	air navigation service provider
Cm	centimeter
C-band	4-8 GHz frequency range of radio spectrum
CAA	Civil Aviation Authority
CME	coronal mass ejection
CPDLC	controller-pilot data link communications
EQN	equatorial latitudes northern hemisphere
EQS	equatorial latitudes southern hemisphere
EUV	extreme ultraviolet
FAR	false alarm rate

FL	flight level
GCR	galactic cosmic rays
GNSS	global navigation satellite system
GPS	global positioning system (United States)
HF	high frequency (3-30 MHz)
HNH	high latitudes northern hemisphere
HSH	high latitudes southern hemisphere
ICAO	International Civil Aviation Organization
ICRP	International Commission on Radiological Protection
Ka-band	26.5 – 40.0 GHz frequency range of the radio spectrum
keV	kilo electron Volt
Kp	A 3 hourly planetary index of geomagnetic activity
Ku-band	12 – 18 GHz frequency range of the radio spectrum
L1	GPS frequency at 1575 MHz
L-band	1-2 GHz frequency range of radio spectrum
LEO	low earth orbit
MEO	medium earth orbit
METP	Meteorology Panel
MNH	middle latitudes northern hemisphere
MOD	moderate
MSH	middle latitudes southern hemisphere
MUF	maximum usable frequency
NCRP	National Council on Radiation Protection and Measurements (United States)
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
nT	nanoTesla — unit of magnetic field measurement
OPMET	Operational meteorological information
PCA	Polar Cap Absorption
POD	probability of detection
RHCP	right hand circular polarization
RNP	required navigation performance
S-band	2-4 GHz frequency range of radio spectrum
SARPs	Standards and Recommended Practices
SATCOM	satellite communications
SEV	Severe
SWPC	Space Weather Prediction Center (United States)
SWXC	Space Weather Centres
TEC	total electron content
UHF	ultra-high frequency (300 – 3000 MHz)
VHF	very-high frequency (30 – 300 MHz)
WMO	World Meteorological Organization

Chapter 1

INTRODUCTION

1.1 GENERAL

1.1.1 From an operations perspective, space weather events occur when the Sun causes disruptions to aviation communications, navigation and surveillance systems, and elevates radiation dose levels at flight altitudes. Space weather events may occur on short time scales, with the effects occurring from almost instantaneously to over a few days.

1.1.2 From a broader perspective, the World Meteorological Organization (WMO) defines space weather to be “The physical and phenomenological state of the natural space environment, including the Sun and the interplanetary and planetary environments.” This more comprehensive definition cuts a broader band across the system to include the slowly varying galactic cosmic rays (GCR) coming from outside the heliosphere, as well as the repetitive high-speed solar wind streams from voids in the solar corona. In summary, not all space weather stems from eruptions but also from variations in the flow of charged particles, photons, and magnetic field.

1.1.3 Space weather forecasts for international air navigation address particular types of disturbances, i.e. solar radiation, geomagnetic and ionospheric storms, and solar flares. In addition, predictions of the slowly varying elements (i.e. GCR and high-speed stream-induced geomagnetic storms) are also produced. These forecasts enable operators the opportunity to be situationally aware and to formulate alternative plans should the impending conditions be of a magnitude and a type that could disrupt normal operations.

1.1.4 The objective of this manual is to enable operators to make informed decisions when space weather impacts occur. A proper balance between operationally relevant information and scientific completeness is sought. In many areas, more scientific rigor and detail could be brought forward but it would not enhance this manual's utility to the aviation community. A more in-depth explanation of the science underpinning the field of space weather science can be found in Appendix 2.

1.2 SPACE WEATHER INDICATORS

1.2.1 The effects of space weather come from processes that are invisible to the human eye. The sole exception is the brilliant auroras spawned by energetic electrons and ions. Energized auroras indicate the deposition of energy into the upper atmosphere and may herald the degradation of communications, navigation, and surveillance of aircraft in the vicinity.

1.2.2 For space weather events, the signs of their occurrence and system impacts are very subtle in real time. Given that, the prime value of space weather information is to enhance situational awareness of the proper functioning of aircraft systems. Anticipating and planning for degraded performance of communications and navigations systems add to the margins of safety. While degraded performance is often unavoidable, being prepared to respond to it with a preconceived plan is most desirable.

1.2.3 On those occasions when the above effects are apparent, the signs of system impacts may include:

- a) erratic, degraded, or unavailable high frequency (HF) voice communications that worsen very quickly, especially when the aircraft is in the sunlit hemisphere or operating in high latitudes and polar regions;
- b) data and voice dropouts on satellite communications (SATCOM) links, especially for frequencies less than 2 GHz;
- c) a variance in positioning between the actual navigation performance (ANP) and the global navigation satellite system (GNSS)-based performance;
- d) reduced availability of GNSS augmentation systems; and
- e) reboot of on-board electronics or display of indications of non-standard performance.

1.2.4 It is not realistic to expect aircrew to be aware of the slowly occurring variations of space weather, or so-called “space climate”, in real time. Nevertheless, indicators such as the change in GCR flux allow an awareness of the variability. The change in GCR flux over an 11-year solar activity cycle (see Appendix 2, Section 3, for explanation of the 11-year solar cycle) is the opposite of the conventional solar cycle — GCR is highest when sunspots are lowest — and may occur twice as much at altitudes where commercial aircraft fly.

1.2.5 Some indicators of this slow GCR flux change may include:

- a) more than normal avionics (computer) inconsistencies and reboots; and
- b) more than normal interruptions of SATCOM for all frequency bands as satellite-borne electronics experience radiation-induced upsets.

1.3 THE HAZARDS

1.3.1 Space weather impacts occur in communications, navigation, surveillance, radiation-sensitive electronics, and human exposure. Beyond the more generic indicators described in Section 1.2, the system impacts may include:

- a) unexpected loss of communications;
 - 1) HF voice and data link, i.e. controller pilot data link communications (CPDLC), on routes where that manner of communications is used;
 - 2) poor or unusable performance in satellite communications;
- b) degraded performance of navigation and surveillance that rely on GNSS;
 - 1) automatic dependent surveillance – broadcast (ADS-B) and/or automatic dependent surveillance – contract (ADS-C) anomalies;
 - 2) sporadic loss-of-lock of GNSS, especially near the equator and post-sunset;
- c) unanticipated non-standard performance of on-board electronics resulting in reboots and anomalies; and
- d) issues related to radiation exposure by aircrew and passengers.

