

**Attachment B**

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**Integrating Space Weather**

**Observations & Forecasts into**

**Aviation Operations**

**“Aviation Space Weather User Service Needs”**

**Space Weather Sub-Group**

**of the Cross Polar Working Group**

**April 2010**

**Aviation Space Weather User Service Needs\***

**Document Prepared**

**by the**

**Space Weather Sub-Group**

**of the**

**Cross Polar Working Group**

\* *This document used to be referred to as a User Requirements document, but the name has been changed to better reflect the content*

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Cover image is a composite of an aircraft landing and an artist’s impression of the Sun-Earth system.

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# Preface

This document has been prepared as part of a Policy Program Study investigating the Integration of Space Weather Observations & Forecasts into Aviation Operations, a study carried out by American Meteorological Society and SolarMetrics in coordination with the FAA, NOAA SWPC, National Science Foundation (NSF), & Next Generation Air Transportation System Joint Planning and Development Office (NextGen/JPDO).

The American Meteorological Society and SolarMetrics policy workshop report (published March 2007) on “Integrating Space Weather Observations & Forecasts into Aviation Operations” recommended that, “**the aviation industry needs to clearly define its requirements for space weather information and how it is incorporated into the operational decision making process**. The Cross Polar Trans East Air Traffic Management Providers’ Working Group (CPWG) was selected to lead the process for defining these User Service Needs, ensuring that all key stakeholders are present at the discussions.

It is important to note that this process was designed to flow from the perspective of the airlines, down to the service providers. The CPWG space weather sub-group that drafted this document strove to avoid anything that resembled onerous regulation; rather it made having the airlines be the driving force that would spell out how much – or how little – space weather information and services were necessary.

Under the direction of the CPWG leadership, a space weather sub-group was organized with the first task of focusing on Aviation Space Weather User Service Needs. This sub-group includes representatives from the airlines, NOAA SWPC, and international members with aviation and space weather expertise.

This User Service Needs document has been prepared by the following sub-group members:

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\* The sub-group would like to acknowledge the work and help of Dave Rome who retired from NAV Canada in December 2008.

Document Work Plan

The work plan of the sub-group included tackling the following main points:

Elicit input from the airlines;

Define the impacts/hazards;

Discuss operational decision-processes for each hazard;

Draught Service Needs/Information Wish Lists (Forecasting, Nowcasting, Warnings, Alerts, etc)

In order to define “user” service needs, it was discussed that this can be tackled in one of two subtly different ways: (i) start with the space weather hazards and environment, and list the operational impacts or; (ii) start with the impact areas and discuss the operational processes and timelines that need to be addressed during any space weather activity.

From the AMS-SolarMetrics Policy Workshop, one of the major findings was that “currently, many aviation operators find space weather information to be too technical and prefer information that aids decision making.” It was decided to use the second method as it is biased towards the operator’s needs. Therefore, while some basic information will be stated, the detailed specifics of the space weather environment and the technical parameters and capabilities will be dealt with by the space weather community and do not need to be included in this documentation.

The group decided to tackle the problem using a scenario based method. The Chicago to Hong Kong Polar route operation was chosen. The information needs for dealing with each of the impact/hazard areas were tackled. Discussion identified problem areas of “What?”, “When?”, and “How?”, is needed, followed by a process of expanding on each of these in detail when they were considered against the operational and dispatch timeline for the route in question.

User Impact and Service Need Codes

In order to allow some cross reference between identified user impacts, user service needs and space weather events the following code format has been adopted within this document:

Aviation User Impact code (AUI-n, where n= 1, 2, 3, etc refers to an impact)

Aviation User Need code (AUN-n, where n = 1, 2, 3, etc refers to a Service Need)

Space Weather Environment & Hazards

In order to understand the hazards to aviation operations, it is important that some understanding is made of the space weather environment. Therefore a summary of the space weather environment and potential impacts is provided in Appendix C to assist the reader to understand the rationale behind the specific User Service Needs.

A definition of space weather is given in Appendix C. For simplicity, the space weather environment is considered to be the volume from Sun-to-Ground and all the variations that take place within that volume.

Terrestrial Aviation Weather

When considering the requirements for future space weather observations, forecasts and information, and in order to make the integration into aviation operations as easy as possible, the document provides commonality, where possible, with terrestrial aviation weather information and services.

Similarly, reference is made within this document to terrestrial weather information classification, type and sources. This is provided to help the space weather information provider understand the processes and policies that currently govern the delivery of terrestrial weather information to the aviation industry.

Global Airspace Designation

The global airspace can be delineated for space weather forecasts, observations and information in many different ways to suit the needs of the aviation industry. There may be some similarities that can be used from the way terrestrial weather is disseminated globally, but the physical properties of certain space weather phenomena occur across much larger areas, sometimes encompassing multiple Flight Information Regions (FIRs) with varying operations and ATC procedures.

Designation may or may not consider using similar regions defined by:

* International Civil Aviation Organization (ICAO) Flight Information Regions (FIRs)
* Volcanic Ash Advisory Centers (VAACs)
* International Space Environment Services (ISES) Regional Warning Centres (RWC’s)

The designation of the aviation global airspace and how it should best be organized in order to support the delivery of space weather information to the aviation users requires further discussion and input from the Air Traffic Management representatives at the CPWG. Input should also be taken from ICAO, World Meteorological Organization (WMO), VAACs and ISES. Therefore, defining this issue is considered to be beyond the scope of this document.

Other Airspace Users

It is recognized that there are other users of the national and global airspace that will have a need for space weather information that will benefit from being communicated, integrated and standardized in the same way as that for commercial airline operations. These operational areas are considered to be:

* Commercial and private business jet operations
* Commercial space transportation operations (e.g., space tourism, launch systems)
* Military operations
* Unmanned Aerial Vehicles (UAVs, both military and commercial operations

Detailed consideration of their requirements is not included in this document. However, representatives from these operational areas may submit input that could be considered for inclusion in annexes to this document.

Action Items

Where any issues or specific clear action items arose during discussions these are identified within the body of this document and the Action Item detailed in Appendix B.

Appendices

Appendices have been included to provide additional information to aid in the understanding of the space weather and radiation issues affecting aviation.

A list of the acronyms used throughout this document is included as Appendix A.

# 1 Executive Summary

The space weather events that concern the commercial air and space industries most are those that disrupt the operational systems and those that increase the radiation environment. The issues are economic, operational and safety related. The effects include degradation or loss of radio frequency (RF) communications and satellite navigation signals; navigation system disruptions; avionic errors and human health.

The American Meteorological Society (AMS) and SolarMetrics, in coordination with the FAA, NOAA/SWPC, NSF, and NextGen/JPDO, organized a workshop on November 29–30, 2006 in Washington DC that led to recommendations on how to improve the safety and operations of the global aviation system through better integration of space weather information.

That workshop identified that there was a need for the aviation industry and the space weather community to have a clearer understanding of the operational requirements for space weather information. Therefore, it was decided that the aviation industry needed to clearly define its needs for space weather information and how it is incorporated into the operational decision making process. The Cross Polar Trans East Air Traffic Management Providers’ Working Group (CPWG) was identified to lead the process for defining these “User Service Needs” through the work of a CPWG Space Weather (SW) sub-group comprising expertise in operations, Air Traffic Management (ATM), and space weather science.

The User Service Needs have been defined first and foremost by their category of operational impact (i.e., communication, navigation, avionic and human health) and then with consideration for the operational processes and timelines that need to be addressed during any space weather activity. This ensures that the defined needs are biased towards the end user (i.e., the operators). Therefore, while some basic information will be stated, the detailed specifics of the space weather environment, the science, and the technical parameters and capabilities will be dealt with by the space weather community and have not been included in this document.

This document defines the identified User Service Needs, which are presented in detail within this document. In addition, any issues or specific action items that arose during the preparation of this document are highlighted within the body of this document and summarized in Appendix B.

User Service Needs from Sections 2, 3 and 4 have been summarized and presented in tables below for quick reference in this Executive Summary.

The time reference used throughout this document is “UTC”.

Here is a summary of the main User Service Need areas:

**Section 2: Aviation Space Weather User Service Needs**

|  |  |  |  |
| --- | --- | --- | --- |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-1 | Define the Impacts | The impacted areas that need to be addressed are:  - Communications  - Disruption of HF  - Interruption of VHF  - Reduced performance of UHF  - Satellite communication  - Radiation  - Avionics  - Humans  - Satellite Navigation | Para 2.1, Table 2-1  (list of Aviation User Impacts) |
| AUN-2 | Types of Information:  - Observations  - Forecasts  - Climatology | 3 sub-types of Observations:  - Warnings  - Alerts  - Updates | Para 2.2 |
| AUN-3 | Text Reports | Follow similar conventions to terrestrial weather METARs and SPECIs | Para 2.2.1 |
| AUN-3.1 | Format and Content:  - Type of report  - Releasing Station identifier  - Affected airspace or region  - Date, time stamp  - Body (the information) | International Civil Aviation Organization (ICAO) format identifier  Airspace or regions yet to be designated | Para 2.2.1.1 |
| AUN-3.1.1 | Severity of Hazard | Should be described in standardized format and terminology | Para 2.2.1.1.1 |
| AUN-3.1.2 | Timelines for reports to be stated:  - Valid from  - Duration of or valid to | Applicable for any report (i.e., forecast, warning, alert, update), and applicable to each hazard | Para 2.2.1.1.2 and Table 2-2 Report Timescales |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-3.1.2  (cont’d) | - Ongoing changes within duration  Reports required:  - 7 day forecast  - 3 day forecast  - 30 hour forecast  - 12 hour forecast  - 6 hour forecast  - 6 hour warning  - Immediate alert  - Update  - Post-Event Analysis (PEA) | Issued:  - Once every 7 days  - Once every 24 hours  - 4 times a day 0000, 0600, 1200, 1800utc  - Once every 3 hours  - Once every 2 hours  - With every new forecast parameter change increase.  - Valid immediately and for a specified time period where the activity is forecast to remain above the parameter action level. New alert issued with further increasing activity that affects parameter action levels.  - For a prior alert parameter change where activity decreases below action levels  Requires data collection procedures |  |
| AUN-3.1.3 | Reliability, % Confidence Levels, Probability of Event Occurring | Accuracy of information: a space weather information provider will be required to state, in their reports, in some way, the reliability or % confidence level of the information provided | Para 2.2.1.1.3  Table 2-3 |
| AUN-3.1.4 | Regions, Boundaries, Volumes can be stated as:  - Latitude/Longitude  - Current airspace regions  - ATM  - Route traffic flow rate impacts  - ICAO Flight | The regions, boundaries and volumes (by defining altitudes and flight levels) that are applicable to the hazard contained within the report should be stated. | Para 2.2.1.1.4 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-3.1.4  (cont’d) | Information Regions (FIRs)  - International Space Environment Service (ISES) regions |  |  |
| AUN-4 | Graphical Reports | Graphical Analysis Charts of space weather observations in a similar manner to current terrestrial Significant Weather charts. | Para 2.2.2 |
| AUN-4.1 | Format and Content:  - Type of chart or report  - Releasing Station identifier  - Regions depicted on chart / report /affected FIR(s) or ATM regions  - Date, time stamp | ICAO format identifier | Para 2.2.2.1 |
| AUN-4.1.1 | Severity of Hazard | Graphical charts / reports required to define:  - the type of hazard  - depict the distribution of severity | Para 2.2.2.2 |
| AUN-4.1.2 | Timelines for reports | Graphical charts / information required to depict:  - “snapshot” of space weather, applicable to each hazard, expected at the specified valid time  - forecasted conditions at four (4) periods, 12-hours, 24-hours, 3-days, 7-days | Para 2.2.2.3 |
| AUN-4.1.3 | Reliability, % Confidence Levels, Probability of Event Occurring | Charts / information required to contain reliability, % confidence levels or probability of event occurring within the time covered by the forecast | Para 2.2.2.4 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-4.1.4 | Combined Space and Terrestrial Weather Hazard Charts | A combined space and terrestrial weather chart should be considered for “big picture” planning | Para 2.2.2.5 |
| AUN-5 | Communicating Space Weather Information  Integrated with Ops / Dispatch:  - Pushed  - Pulled  - “attention-getters” with Ops / Dispatch | Information, reports, charts required to be communicated:  - via all the currently available and regulatory approved transmission methods  - via regulated Internet methods (i.e., Qualified Internet Communications Provider)  - “pushed” or “pulled”  Warnings, Alerts, Parameter Alerts/Drop-offs, Text & Alert graphics  Forecasts, Analysis Chart graphics  Warnings, Alerts, Drop-offs | Para 2.2.3 |
| AUN-6 | RF Communication |  | Para 2.2.4 |
| AUN-6.1 | HF communications  - Severity  - Timescales  - Reliability, % Confidence Levels, Probability of Event | Information required:  - Signal strength/loss  - Clarity  - Best Useable Frequencies  - Valid from  - Duration or Valid to  - Ongoing changes  - Confidence levels  - Current Condition Reports  - 7 days – 65%  - 3 days – 75%  - 30 hours – 85% | Para 2.2.4.1  Table 2-4 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-6.1  (cont’d) | Occurring  - Regions / Boundaries / FIR  - Hazard cause | - 12 hours – 95%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99%  Regions, boundaries required to be defined, applicable to the hazard contained within the reports  Allows for differing operational responses |  |
| AUN-6.2 | VHF communications  - Severity  - Timescales  - Reliability, % Confidence Levels, Probability of Event Occurring  - Regions / Boundaries / FIR | Information required:  - Signal strength/loss  - Clarity  - Susceptible Frequencies  - Valid from  - Duration or Valid to  - Ongoing changes  - Confidence levels  - Current Condition Reports  - 7 days – not required  - 3 days – not required  - 30 hours – 65%  - 12 hours – 85%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99%  Regions, boundaries of hazard required to be defined | Para 2.2.4.2  Table 2-5 |
| AUN-6.3 | UHF communications  - Severity | Information required:  - Signal strength/loss  - Clarity  - Susceptible Frequencies | Para 2.2.4.3 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-6.3  (cont’d) | - Timescales  - Reliability, % Confidence Levels, Probability of Event Occurring  - Regions / Boundaries / FIR | - Valid from  - Duration or Valid to  - Ongoing changes  - Confidence levels  - Current Condition Reports  - 7 days – 65%  - 3 days – 75%  - 30 hours – 85%  - 12 hours – 95%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99%  Regions, boundaries of hazard required to be defined | Table 2-6 |
| AUN-6.4 | Satcom  - Severity  - Timescales  - Reliability, % Confidence Levels, Probability of Event Occurring | Information required:  - Signal strength/loss  - Clarity  - Susceptible Frequencies  - Valid from  - Duration or Valid to  - Ongoing changes  - Confidence levels  - Current Condition Reports  - 7 days – not required  - 3 days – not required  - 30 hours – 65%  - 12 hours – 85%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99% | Para 2.2.4.4  Table 2-7 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-6.4  (cont’d) | - Regions / Boundaries / FIR | Regions, boundaries of hazard required to be defined |  |
| AUN-7 | Radiation – Avionics  - Severity  - Timescales  - Reliability, % Confidence Levels, Probability of Event Occurring  - Regions / Boundaries / FIR  - Altitudes / Flight Levels / Volumes | Information required:  - Galactic radiation dose rates  - Solar radiation dose rates  - Rate of change of dose rates (up & down)  - Peak dose rates  - Avionics risk factor  - Particle spectra – for Post-Event Analysis  - Valid from  - Duration or Valid to  - Ongoing changes  - Confidence levels  - Current Condition Reports  - 7 days – 65%  - 3 days – 75%  - 30 hours – 85%  - 12 hours – 95%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99%  Regions, boundaries of hazard required to be defined  Required to be defined | Para 2.2.5  Table 2-8 |
| AUN-8 | Radiation – Humans  - Severity | Information required:  - Galactic radiation dose rates  - Solar radiation dose rates  - Rate of change of dose | Para 2.2.6 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-8  (cont’d) | - Timescales  - Reliability, % Confidence Levels, Probability of Event Occurring  - Regions / Boundaries / FIR  - Altitudes / Flight Levels / Volumes | rates (up & down)  - Peak dose rates  - Dose rate conversion to Human Exposure risk factor  - Event spectra – for Post-Event Analysis  - Valid from  - Duration or Valid to  - Ongoing changes  - Confidence levels  - Current Condition Reports  - 7 days – 65%  - 3 days – 75%  - 30 hours – 85%  - 12 hours – 95%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99%  Regions, boundaries of hazard required to be defined  Required to be defined | Table 2-9 |
| AUN-9 | Satellite Navigation  - Severity  - Timescales | Information required:  - Max horizontal & vertical inaccuracies  - Rate of onset  - Outages  - Airfield approach category drops  - WAAS, LAAS, RNP confidence levels  - Valid from  - Duration or Valid to  - Ongoing changes | Para 2.2.7 |
| **Aviation User Need No. (AUN)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-9  (cont’d) | - Reliability, % Confidence Levels, Probability of Event Occurring  - Regions / Boundaries / FIR / Volume  - Airfields / Runways | - Confidence levels  - Current Condition Reports  - 7 days – 75%  - 3 days – 85%  - 30 hours – 95%  - 12 hours – 95%  - 6 hours – 95%  - Alerts – 95%  - Updates – 95%  - PEA – 99%  Regions, boundaries of hazard required to be defined  Required to be defined for each | Table 2-10 |
| AUN-10 | Operational Decision Processes | Requirement to define the appropriate operational and ATM decision-makers that should receive space weather information | Para 2.3, Table 2-11a and Table 2-11b |

**Section 3: Communicating Aviation Space Weather Information**

|  |  |  |  |
| --- | --- | --- | --- |
| **Aviation User Need No. (AUR)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-12 | Communicating space weather information | Requirements for dissemination, formatting, integration, education and training | Section 3 |
| AUN-12.1 | Dissemination of space weather information | Requirements to define the key stakeholders to receive space weather information | Para 3.1  (refer to Table 2-11a, 2-11b) |
| AUN-12.2 | Formatting and integration with terrestrial weather | Requirements for minimum operational briefing standards and services | Para 3.2 |
| AUN-12.3 | Space weather education and product training | Requirements to generate a standardized aviation space weather education and training curriculum | Para 3.3 |

**Section 4: Standardizing Aviation Space Weather Information**

|  |  |  |  |
| --- | --- | --- | --- |
| **Aviation User Need No. (AUR)** | **User Need** | **Notes** | **Document Section reference** |
| AUN-11 | Aviation Space Weather Classification and Policy | Requirements for classification, description of types of information and categorization of sources | Section 4 |
| AUN-11.1 | Classification of space weather information | Information required to be designated as:  - Primary SW Information  - Supplementary SW Information | Para 4.1 |
| AUN-11.2 | Types of space weather information | Types required:  - Observations  - Analysis  - Forecasts | Para 4.2 |
| AUN-11.3 | Categorizing space weather aviation sources | Required categorization:  - Federal Government  - Commercial SW Information Providers | Para 4.3 |

# 2 Aviation Space Weather User Service Needs

The sub-group used the Chicago to Hong Kong Polar route operation to consider what space weather observations and forecasts are required for each of the impacted areas of the operation.

It is recognized that observations will be the basic starting point from which future forecasts and warnings will be developed as the space weather community improves its scientific capabilities of understanding the space weather environment. However, in order to support the scientific and technical development this section will include requirements for observations, forecasts and warnings. Similarly, while the sub-group recognizes there are scientific and technical limitations in what the space weather community can currently (and for some time into the future) provide, the user requirements defined here have been kept deliberately demanding with no compromise from the absolute ideal.

## 2.1 Define the impacts/hazards

The impacted areas that need to be addressed are RF Communications (HF primarily considered here, but VHF, UHF and Satcom), Radiation (separated in to Avionics and Humans) and Satellite Navigation (Global Navigation Satellite System [GNSS]).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **AUI No.**  **(AUI-n)\*** | **Impact/Hazard** | **Cause** | **Consequence** | **Locality** | **SW Related Events** |
| AUI-1 | RF Comms |  |  |  |  |
| AUI-1a: HF | Disruption/loss of HF comms | Ionospheric irregularities:  (i) Dayside absorption  (ii) Polar Cap Absorption  (iii) Auroral Absorption | Non-compliance with FAR 121.99  Unable to make position reports | (i) Mid & low latitudes (dayside)  (ii) Polar regions  (iii) Auroral latitudes | Solar EUV during flares  Solar Particle Events (SPEs)  Geomagnetic storms |
| AUI-1b: VHF | Interruption of VHF comms | Solar flare radio noise | Direct interruption  Indirect effect on satellite links | Sunlight side | Solar Radio Noise |
| AUI-1c: UHF (military) | Reduced operational performance | Ionospheric irregularities | Errors in radar, altimetry and geo-location | Global | Geomagnetic storms |
| AUI-1d: Satcom | Fading &  Loss of lock | Ionospheric variability | Signal drop-out & noise | Global | Geomagnetic storms |
| **AUI No.**  **(AUI-n)\*** | **Impact/Hazard** | **Cause** | **Consequence** | **Locality** | **SW Related Events** |
| AUI-2 | Radiation |  |  |  |  |
| AUI-2a: Avionics | Single Event Effects (SEE) | Ionizing Radiation:  Energy > 10MeV | Radiation damage to avionics  Induced Software errors | Polar / High latitude routes, High altitude aircraft  (Reusable Launch Vehicles – RLVs  Expendable Launch Vehicles - ELVs) | Galactic Cosmic Rays (GCR)  Solar Cycle  SPEs |
| AUI-2b: Humans | Radiation Exposure | Ionizing Radiation:  Energy > 10MeV | Radiation dose to aircrew and passengers | Polar / High latitude routes, High altitude aircraft  (Reusable Launch Vehicles – RLVs  Expendable Launch Vehicles - ELVs) | GCRs  Solar Cycle  SPEs |
| AUI-3: Satellite Navigation | Interruption to GNSS for navigation | Ionospheric scintillations  Solar Radio Bursts | Errors in positioning used for navigation, approach and landing  Signal Loss | Mainly equatorial and auroral latitudes | Solar EUV during flares  Geomagnetic storms  SPEs |

Table 2-1. Aviation User Impact/Hazards. \* AUI No. = Aviation User Impact code

## 2.2 Types of Information Required

Aviation space weather decision information is required to be divided into three main types:

* Observations – Determined now and effective for several minutes or hours before subsequent observations overwrite the prior information. Observations should describe current space weather conditions. There should be three sub-types of observations:
* Warnings
* Alerts
* Updates (Now-casts and parameter changes)
* Forecasts – Describing future space weather conditions minutes, hours, or days into the future, forecasts should employ satellite data, space weather models and correlate multiple information sources to reveal expected future conditions for strategic planning.
* Climatology – Describing past space weather conditions that may be used by models to characterize events leading up to the current state and used to interpret space weather phenomena over time, and for post event analysis of commercial, operational, safety and technological impacts.

## 2.2.1 Text Information

Observations will be the basic information upon which forecasts, warnings, alerts and updates are made in support of aviation activities.

Aviation Routine Weather Reports (METAR) and Selected Special Weather Reports (SPECI) are the terrestrial weather text information that are the primary observation codes used worldwide. Examples of terrestrial weather forecasts are Area Forecasts (FA) and Terminal Aerodrome Forecast (TAF). These follow similar conventions to METAR and SPECI. The format and criteria of these terrestrial information should be considered for delivering space weather forecasts, warnings and alerts.

Space weather information should be standardized in format and content in line with agreed WMO and ICAO requirements.

## 2.2.1.1 Format and Content

The space weather information report should contain the following:

* Type of report (i.e., observation/forecast/climatology, applicable impact area)
* Releasing station or source provider (i.e., ISES RWC) identifier (using ICAO format)
* Affected FIR(s) or ATM regions
* Day, month and time of report

The body of the report should provide detailed information of the actual space weather forecast, warning, alert or update.

## 2.2.1.1.1 Severity of Hazard

The severity of the hazard should be described in standardized format and terminology.

The aviation-related NOAA Space Weather Scales must be adapted to reflect this new terminology.

## 2.2.1.1.2 Timelines of Information

The timeline for the report (forecast, warning, alert or update), applicable to each hazard, is required to state:

* Valid from, including Day of Month
* Duration or valid to
* Ongoing changes within duration

Table 2-2 below depicts the type of information or report required (will vary by hazard) versus the required look ahead timescales.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast |  |  |  |  |  |  |  |
| Warning |  |  |  |  |  |  |  |
| Alert |  |  |  |  |  |  |  |
| Update |  |  |  |  |  |  | Parameter Changes |
| Post-Event Analysis |  |  |  |  |  |  |  |

Table 2-2. Reports and timescales. (Note: specific hazard paragraphs below will show either an “x” in a box depicting a requirement for that report or a [number]% depicting a desired reliability or confidence level for that report)

The required timescales specified in the table above are as follows:

* 7 days Forecast – A summary forecast (or “Outlook”) describing the space weather conditions (for all hazards) for the next 7 days from the stated valid from time. Should be issued once every 7 days.
* 3 days Forecast – A forecast describing the space weather conditions (for the specified hazard) for the next 3 days from the stated valid from time. Should be issued once every 24 hours.
* 30 hours Forecast – A forecast describing the space weather conditions (for the specified hazard) valid for the next 30 hours. Should be scheduled to be issued four (4) times per day, at 0000, 0600, 1200, and 1800 UTC.
* 12 hours Forecast – A forecast describing the space weather conditions (for the specified hazard) valid for the next 12 hours. Should be scheduled to be issued every three (3) hours.
* 6 hours Forecast – A forecast describing the space weather conditions (for the specified hazard) valid from the issue time for the next 6 hours. Should be scheduled to be issued on the hour every two (2) hours.
* 6 hours Warning – A warning of possible space weather activity that could result in parameter changes affecting the specified hazard for the next 6 hours. A new 6 hour warning should be issued with every new forecast parameter change increase.
* 0 time or “Immediate” Alert – An alert where space weather activity has produced a parameter change that affects the specified hazard. Valid immediately and for a specified time period where the activity is forecast to remain above the parameter action level. New alerts should be issued with further increasing activity that affects parameter action levels.
* Update – Should be issued for a prior alert parameter change where activity decreases below action levels.
* Post-Event Analysis (PEA) – Collection of space weather data (events, parameters, etc) and operational reactions should be included in space weather services. (*Note: Users and space weather service providers require post-event data to determine whether systems failed as a result of space weather events or whether decisions made mitigated the impacts. It will also enable long-term feedback into design, development of more reliable models and predictions, better risk assessment, better mitigation procedures and better understanding and education.*)

## 2.2.1.1.3 Reliability, % Confidence Levels or Probability of Event Occurring

Terrestrial weather forecasters use the probability group, PROB30, to forecast a low probability occurrence (30%) of a weather event at an airport. (U.S. military and International forecasters may also use the PROB40 [40% chance]). A beginning and end time (in hours) of the expected conditions will be given for each PROB30.

Space weather events can affect very large airspace volumes over long timescales, with large commercial impacts. Operational decision-makers therefore need to have increased confidence in all space weather forecasting and reporting. Reporting of the space weather events that may give rise to the various hazards will require different reliability, % confidence levels or probability of event occurrence for each of the information timescales. The reliability or % confidence level in the accuracy of the information provided is required to be stated in the service or report notes.

Examples for the required % confidence levels (of an accurate forecast or report) for each of the timescales are given in Table 2-3 below:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | 65-85% | 65-85% | 75-95% | 75-95% | 95% |  |  |
| Warning |  |  |  | 95% | 95% |  |  |
| Alert |  |  |  |  |  | 95% |  |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-3. Example table of required % confidence levels for report information. The reliability, % confidence levels could vary depending on the particular hazard.

Current Condition remarks are required in support of the reliability targets.

## 2.2.1.1.4 Regions, Boundaries and Volumes

The designation of the aviation global airspace and how it should best be organized in order to support the delivery of space weather information to the aviation users requires further discussion and is beyond the scope of this document. **Action Item AI-01**

However, once the designation is defined, the regions, boundaries and volumes (by defining altitudes and flight levels) that are applicable to the hazard contained within any space weather report should be stated.

The regions, boundaries and volumes could be stated in one or more of the following ways:

* Latitude and Longitude **Action Item: AI-02**
* ICAO FIRs
* VAACs
* ISES RWC regions
* Altitudes/Flight Levels

## 2.2.2 Graphical Observations and Derived Information

Consideration should be given to the development of Analysis Charts of space weather observations in a similar manner to current terrestrial Significant Weather charts. The charts could be single hazard charts or combine several hazards onto one chart.

## 2.2.2.1 Format and Content

The space weather graphical information should state the following:

* Type of chart / information
* Releasing Station (i.e., ISES RWC) identifier (ICAO format)
* Regions depicted on chart / information /affected FIR(s) or ATM regions
* Date and time of chart / product

## 2.2.2.2 Severity of Hazard

Graphical observations should define the type of hazard shown and depict the distribution of severity through the use of color (i.e., traffic light system – red, yellow, green) and/or shading.

## 2.2.2.3 Timelines of Information

The charts / information depict a “snapshot” of space weather, applicable to each hazard, expected at the specified valid time. The forecasted conditions should be divided into four forecast periods, 12-, 24-hours, 3-days, and 7-days.

## 2.2.2.4 Reliability or % Confidence Levels

The graphical representations of space weather hazards should also contain information relating to the reliability or % confidence levels of the forecasts.

## 2.2.2.5 Combined Space and Terrestrial Weather Hazard Charts

The ability to react to space weather hazards must also take into account the terrestrial weather through or over which aircraft are flying. A combined space and terrestrial weather chart should be considered for “big picture” planning (see Figure 2-1).

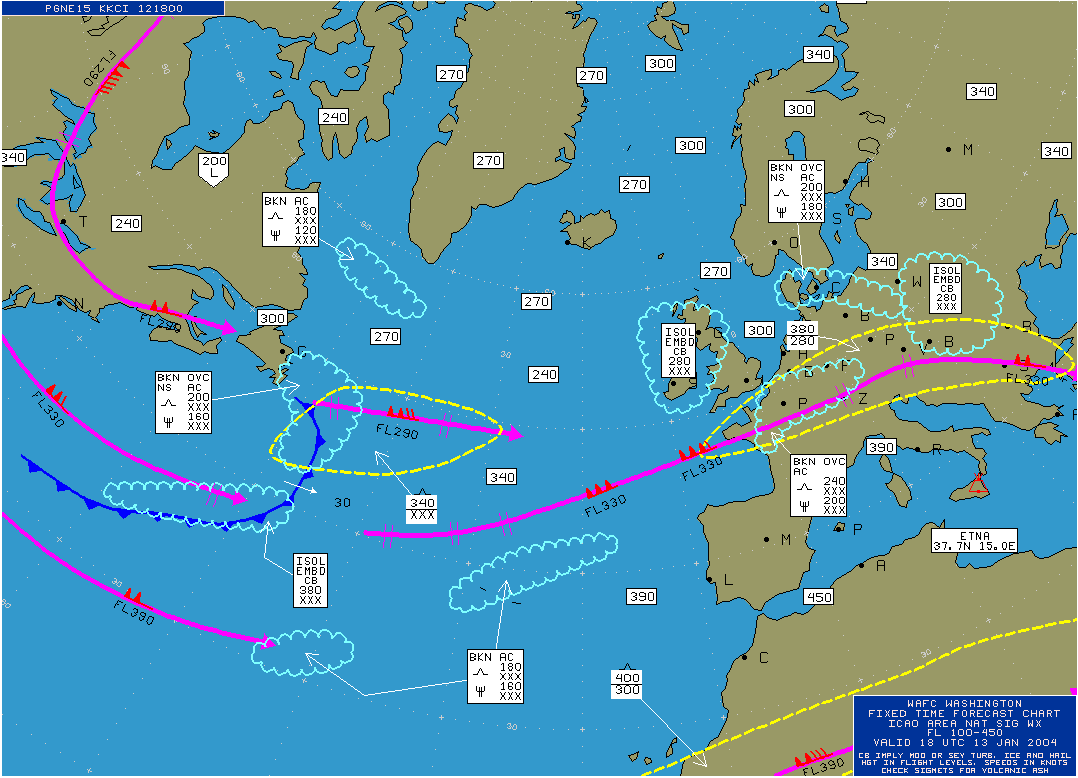


Fig 2-1. Example of Significant Weather Chart that could be used to superimpose Space Weather information

## 2.2.3 Communicating Space Weather Information

Space Weather information and reports should be communicated to the industry via all the currently available and regulatory approved transmission methods.

The graphical charts and derived information should be transmitted from approved sources via the Internet.

Communication of information should be possible either by being “pushed” or “pulled” and where required, integrated with the Operations/Dispatchers work area as follows:

* Pushed – Warnings, Alerts, Parameter Alerts/Drop-offs, text & Alert graphics
* Pulled – Forecasts, Analysis Chart graphics
* “Attention-getters” with Ops/Dispatch – Warnings, Alerts, Drop-offs

## 2.2.4 RF Communications

### 2.2.4.1 High Frequency (HF) Disruptions

In general, the exact space weather cause of any HF disruption will not be important to the dispatcher-pilot briefing. However, 3 different causes of HF disruption have been identified, each with its own particular characteristics and durations. Therefore, in the case of polar operations, the observed effects may possibly allow different operational windows and flow control/spacing procedures.

For loss or disruption of HF Communications the Decision-makers require the following information:

* Severity
  + Signal strength/loss
  + Clarity
  + Best Useable Frequencies
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | 65% | 75% | 85% | 95% | 95% |  |  |
| Warning |  |  |  | 95% | 95% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-4. Timescale and confidence level requirements for HF Communications Information

* Region/Boundaries/FIR
* Hazard cause – differing operational responses

Other considerations that will affect the requirements are:

- Global airspace breakdown

- increase use of CPDLC

- implementation of Satcom systems

- NextGen, SESAR

### 2.2.4.2 Very High Frequency (VHF) Disruptions

Space weather events occur that cause an increase in ionization in the lower regions of the ionosphere on the sunlit side of Earth. The sudden ionospheric disturbance (SID) of radio signals can take place at VHF as well HF and may appear as a short-wave fade (SWF). This disturbance may last from minutes to hours, depending upon the magnitude and duration of the event. Other space weather events also create a wide spectrum of radio noise; at VHF (and under unusual conditions at HF) this noise may interfere directly with a wanted signal.

For loss or disruption of VHF Communications the Decision-makers require the following information:

* Severity
  + Signal strength/loss
  + Clarity
  + Susceptible Frequencies
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | n/r | n/r | 65% | 65% | 85% |  |  |
| Warning |  |  |  | 65% | 85% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-5. Timescale and confidence level requirements for VHF Communications Information (n/r – not required)

* Region/Boundaries/FIR

2.2.4.3 Ultra High Frequency (UHF) Disruptions

A line-of-sight signal loss due to space weather activity. Primarily more of interest to military radar systems.

For loss or disruption of UHF Communications the Decision-makers require the following information:

* Severity
  + Signal strength/loss
  + Clarity
  + Susceptible Frequencies
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | 65% | 75% | 85% | 95% | 95% |  |  |
| Warning |  |  |  | 95% | 95% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-6. Timescale and confidence level requirements for UHF Communications Information

* Region/Boundaries/FIR

2.2.4.4 Satellite Communication Disruptions

This issue is one primarily to do with the loss of the line-of-sight VHF/UHF signals to the satellite, but can be classed as satellite communication disruption. For loss or disruption of Satellite Communications the Decision-makers require the following information:

* Severity
  + Signal strength/loss
  + Clarity
  + Best Useable Frequencies
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | n/r | n/r | 65% | 65% | 85% |  |  |
| Warning |  |  |  | 65% | 85% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-7. Timescale and confidence level requirements for Satellite Communications Information (n/r – not required)

* Region/Boundaries/FIR

## 2.2.5 Radiation - Avionics

Require distribution of Institute of Electrical and Electronics Engineers (IEEE) Standards on Avionics to industry along with an internationally accepted radiation effects on avionics education syllabus.

For the environmental radiation levels at all aircraft altitudes the Decision-makers require the following information:

* Severity
  + Galactic radiation dose rates
  + Solar radiation dose rates
  + Rate of change of dose rates (up & down)
  + Peak dose rates
  + Avionics risk factor
  + Particle spectra – for Post-Event Analysis
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | 65% | 75% | 85% | 95% | 95% |  |  |
| Warning |  |  |  | 95% | 95% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-8. Timescale and confidence level requirements for Radiation (Avionics) Environment Information

* Region/Boundaries/FIR
* Altitudes/Flight Levels/Volumes

## 2.2.6 Radiation - Humans

Require internationally accepted radiation exposure/health monitoring guidelines, plus education syllabus.

For the environmental radiation levels at all aircraft altitudes the Decision-makers require the following information:

* Severity
  + Galactic radiation dose rates
  + Solar radiation dose rates **Action Item AI-03**
  + Rate of change of dose rates (up & down)
  + Peak dose rates
  + Dose rate conversion to Human Exposure risk factor
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | 65% | 75% | 85% | 95% | 95% |  |  |
| Warning |  |  |  | 95% | 95% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-9. Timescale and confidence level requirements for Radiation (Human) Environment Information

* Region/Boundaries/FIR
* Altitudes/Flight Levels/Volumes

## 2.2.7 Satellite Navigation

A general approach to GNSS has been taken. Specific performance of the different National GNSS (i.e., GPS, Galileo, etc) has not been addressed at this stage.

For loss or disruption of HF Communications the aviation decision-makers require the following information:

* Severity
  + Max horizontal & vertical inaccuracies
  + Rate of onset
  + Outages
  + Airfield approach category drops
  + WAAS, LAAS, RNP confidence levels
* Timescales
  + Valid from
  + Duration or Valid to
  + Ongoing changes
  + Confidence levels
  + Current Condition Reports

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 7 days | 3 days | 30 hours | 12 hours | 6 hours | 0  Dispatch | → |
| Forecast | 75% | 85% | 95% | 95% | 95% |  |  |
| Warning |  |  |  | 95% | 95% |  |  |
| Alert |  |  |  |  |  | 95% | 95% |
| Update |  |  |  |  |  |  | 95%  Parameter Changes |
| PEA |  |  |  |  |  |  | 99% |

Table 2-10. Timescale and confidence level requirements for Satellite Navigation Information

* Region/Boundaries/FIR/Volume
* Airfields/Runways

## 2.3 Operational Decision Processes

There is a requirement to ensure that space weather information is delivered to all the appropriate operational and ATM decision-makers. The following are the suggested space weather information / decision-maker matrices. The tables are based upon similar decision areas and criteria taken from the latest NextGen draft document for the Preliminary Performance Requirements (Version 0.2c, September 10, 2008).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Decision-Makers | Airline Dispatchers | | | Pilots1 | | | | | | En Route Controllers | | | | Oceanic Controllers | | Approach/Departure Controllers | | | Local Controllers | |
| Decisions  Information Types | Route/Altitude Selection | Go/No Go Decision | In-flight Route/Altitude Change | Route/Altitude Selection | Go/No Go Decision | In-flight Route/Altitude Change | Hazardous Weather Deviation | Approach Commencement | Landing Decision | Metering/Spacing Decision | Route/Altitude Selection | Approach/Departure Route Selection | Approach/Departure Clearance | Metering/Spacing Decision | Route/Altitude Selection | Metering/Spacing Decision | Route/Altitude Selection | Arrival/Departure Route Selection | Metering/Spacing Decision | Runway Selection |
| Disruption/loss of HF Comms | x | x | x | x | x | x | x |  |  | x | x |  |  | x | x |  |  |  |  |  |
| Interruption of VHF Comms |  |  |  |  |  | x | x | x | x |  |  |  | x |  |  |  |  |  |  |  |
| Reduced UHF Performance2 |  |  |  |  |  | x | x |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Interruption of SatCom |  |  | x |  |  | x | x |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Radiation Environmental levels and variability | x | x | x | x | x | x | x |  |  | x | x |  |  | x | x |  |  |  |  |  |
| GNSS integrity, accuracy and outages | x |  |  |  |  | x |  | x | x | x | x |  | x | x | x | x |  | x | x | x |
| Airport/Spaceport SW Reports | x | x | x | x | x | x | x | x | x | x |  | x | x | x |  | x |  | x | x | x |
| Airport/Spaceport Terminal SW Forecasts | x | x | x | x | x | x |  |  |  |  |  |  |  |  |  |  |  |  | x |  |
| En Route SW Forecasts | x | x |  | x | x | x |  |  |  | x | x |  |  | x | x |  |  |  |  |  |
| SW Alerts and Warnings | x | x | x | x | x | x | x | x | x | x | x | x |  | x | x | x |  | x | x | x |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Decision-Makers | NAS Traffic Managers | | | | | Approach/Departure Traffic Managers | | | | | Air Route Traffic Managers | | | | | Airport Managers3 | Aerospace Operators/ Controllers (Space Operations Centers) 4 | | | | Spaceport Operators4 |
| Decisions  Information Types | Airport Acceptance Rate Determination | Ground-Stop/Delay Decision | Route Change | SWAP Implementation | Metering/Spacing Decision | Airport Acceptance Rate Determination | Ground-Stop/Delay Decision | Route Change | SWAP Implementation | Metering/Spacing Decision | Airport Acceptance Rate Determination | Ground-Stop/Delay Decision | Route Change | SWAP Implementation | Metering/Spacing Decision | Airport, Runway Utilization | Departure Location/Trajectory Decision | Go/No-Go Launch Decision | Abort Decision | In-Flight Trajectory Change | Spaceport, Runway Utilization |
| Disruption/loss of HF Comms |  | x | x | x | x |  | x | x | x | x |  | x | x | x | x |  |  |  |  |  |  |
| Interruption of VHF Comms | x | x |  |  | x | x | x |  |  | x | x | x |  |  | x | x |  | x | x |  | x |
| Reduced UHF Performance2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Interruption of SatCom |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Radiation Environmental levels and variability |  |  | x | x | x | x |  | x | x | x |  |  | x | x | x |  | x | x | x | x | x |
| GNSS integrity, accuracy and outages | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |  |  | x |
| Airport/Spaceport SW Reports | x | x | x | x | x | x | x |  | x | x | x |  |  |  |  | x | x | x |  |  | x |
| Airport/Spaceport Terminal SW Forecasts | x | x | x | x |  | x | x |  | x |  | x | x | x | x |  | x | x | x |  |  | x |
| En Route SW Forecasts | x |  | x | x | x | x |  |  |  | x | x |  | x | x | x |  |  |  |  |  |  |
| SW Alerts and Warnings | x | x | X | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |

Tables 2-11a/2-11b. Space Weather information versus Decision-maker matrices.

Note: “x” indicates the user requires this information for their decision.

1 Includes military pilots.

2 Included for military operations.

3 Includes Commanders and Operations Officers.

4 Included as the developing sub-orbital Commercial Space industry will need to integrate their operations into the NextGen NAS.

The inclusion of UAV operations and infrastructure should be considered.

# 3 Communicating Aviation Space Weather Information

These User Service Needs are designed to flow from the perspective of the airlines and operators, down to the service providers, without resembling additional onerous regulation on the end user. It is for the airlines to be the driving force that will spell out how much – or how little – space weather information and services are necessary.

The method of delivery and integration of terrestrial weather information into daily aviation operations is well defined, well regulated and clearly understood by the global aviation industry. From an End User perspective it would be beneficial if the communication of space weather information were to adopt similar practices and protocols, so that it integrated seamlessly into the operation.

Therefore, this section is used to demonstrate how space weather information, where needed, could be integrated into the operation alongside terrestrial weather for the end users, but also provide information to space weather providers on how to communicate with the aviation industry.

## 3.1 Dissemination of Space Weather Information

Pilots and Aircraft Dispatchers will be the ultimate users of Space Weather information services. However, in order that the “big picture” is available to all decision-makers at all levels of the operation then it is required that Space Weather information and services should disseminated in a similar manner to terrestrial weather.

The relevant information and services should also be made available to maintenance and engineering personnel for post-event analysis in the case of avionic upsets and GNSS outages.

The current methods used for communicating aviation-related weather information should be utilized to disseminate space weather information. This should provide the information in a timely and effective manner, in line with terrestrial weather data. The space weather information should be approved for transmission as text via existing systems and as graphical information via approved internet systems.

## 3.2 Formatting and Integration with Terrestrial Weather Information

In the interest of safety, and in order to integrate aviation space weather information into the flight planning and briefing processes, the information should be included in the normal terrestrial weather briefing pack that all pilots, dispatchers and ATC personnel read before each flight or shift.

Like terrestrial weather, and in the near term, the use of Significant Meteorological Information (SIGMETs) could provide a suitable template, format and approved medium for delivering space weather information. SIGMETs provide a concise description of the occurrence or expected occurrence of specified en route weather phenomena which may affect the safety of aircraft operations. SIGMETs are intended for dissemination to all pilots in flight to enhance safety. SIGMETs are issued by the responsible Meteorological Watch Office (MWO) as soon as practical to give notice to operators and aircrews of potentially hazardous en-route conditions. Standard WMO formatting should be adopted.

Examples of other methods of communicating weather information are given in Para’s 3.2.2 and 3.2.3 below. Although there may be National differences, the intention is to show how and where space weather information may be integrated, and not impose particular National practices.

In the mid-to-far term (i.e., NextGen, SESAR), space weather information should be developed that will deliver more detailed information for each of the hazards. The information should be presented in text and graphical formats.

## 3.2.1 Space Weather Briefings

Prior to every flight, pilots and airline dispatchers should gather all information vital to the nature of the flight. This should include appropriate space weather information applicable to the operation and obtained from a recognized source.

In order to provide appropriate space weather information, the providers should deliver the information in the same types of briefings that are currently used for terrestrial weather - a standard, abbreviated or outlook.

Terrestrial weather information can be recorded in the flight plan system and a note is made regarding the type of weather briefing provided. Integrating space weather information would also then be included in this. If necessary, this information can then be referenced later to file or amend a flight plan. It can also used when an aircraft is overdue, reported missing or for post-event analysis.

3.2.1.1 Standard Briefing

The space weather standard briefing should provide a complete space weather picture and is the most detailed of all briefings. This type of briefing should be available prior to the departure of any flight and should be considered during flight planning. A standard briefing provides the following information in sequential order if it is applicable to the route of flight.

1. Adverse Conditions - This should include information about adverse conditions that may influence a decision to cancel or alter the route of flight. Adverse conditions include significant space weather such as loss or disruption of communications, increased levels of radiation at planned altitudes, GNSS outages or inaccuracies effecting navigation.

2. Synopsis - The synopsis should be an overview of the larger space weather picture. Solar activity (i.e., sunspots, flares, etc), geomagnetic storms and activity, ionospheric variations, aurora borealis/australis and the resulting major space weather effects along or near the intended route of flight.

3. Current Conditions - This portion of the briefing should contain the current space weather observations effecting communications, radiation and navigation along the route of flight. If the departure time is more than 2 hours away, current conditions should not be included in the briefing. Nil activity, effects and degradation should be stated.

4. En Route Forecast - The en route forecast should be a summary of the space weather forecast effecting communications, radiation and navigation for the proposed route of flight.

5. Communication Frequency Forecast – This forecast, where applicable for the intended flight, should provide detailed information on the best (max) useable HF frequencies, with a time period, in each ATC Flight Information Region (FIR).

6. Destination GNSS Forecast - The destination GNSS forecast should be a summary of the expected GNSS reliability and accuracy for the anticipated arrival and runway at the destination airport at the estimated time of arrival (ETA).

7. Radiation Aloft – Radiation aloft should be a forecast of the atmospheric radiation dose rates at specific altitudes along the route of flight.

8. ATC Delays - This should be an advisory of any known or anticipated ATC delays or spacing variations, due to space weather activity, that may affect the flight.

9. Other Information - At the end of the standard briefing, the specialist or service provider should provide telephone number information to contact their services or for the National ISES Regional Warning Centre (RWC). Airborne radio frequencies to contact En Route Flight Advisory Services (EFAS) should also be considered. Any additional information requested should also be provided in this section.

3.2.1.2 Abbreviated Briefing

The space weather abbreviated briefing is a shortened version of the standard briefing. It should be requested when a departure has been delayed or when specific space weather information is needed to update a previous standard briefing. When this is the case, the space weather specialist will need to know the time and source of the previous briefing so the necessary space weather information will not be omitted inadvertently.

3.2.1.3 Outlook Briefing

The outlook briefing should be requested when a planned departure is 6 or more hours away. It should provide initial forecast information, but will be limited in scope due to the timeframe of the planned flight. This type of briefing should be a good source of flight planning information that can influence decisions regarding route of flight, altitude, and ultimately the “go, no-go” decision. A follow-up standard briefing prior to departure will be required.

## 3.2.2 Aviation Digital Data Service (ADDS) (or Equivalent)

The Aviation Digital Data Service (ADDS) provides the aviation community with text, digital and graphical forecasts, analyses, and observations of aviation-related terrestrial weather variables. ADDS is a joint effort of NOAA Forecast Systems Laboratory (FSL), NCAR Research Applications Laboratory (RAL), and the AWC.

Space Weather should be included into the ADDS.

## 3.2.3 In-flight Services

For those pilots already in flight and needing space weather information and assistance, the following services currently provided by Flight Service Stations (FSS) for delivering terrestrial weather should be considered for delivering Space Weather Alerts and Warnings in their broadcasts. They can be accessed over the proper radio frequencies printed in flight information publications.

In all cases, pilots should also be able to obtain in-flight space weather information via their airline operations.

3.2.3.1 Hazardous In-flight Weather Advisory Service

Hazardous In-Flight Weather Advisory Service (HIWAS) is a national program for broadcasting hazardous terrestrial weather information continuously over selected navigational aids (NAVAIDs). These broadcasts are only a summary of the information, and pilots contact their operations, an FSS or En Route Flight Advisory Service (EFAS) for detailed information.

The HIWAS broadcast area is defined as the area within 150 NM of HIWAS outlets. The service is provided 24-hours a day. An announcement is made for no hazardous weather advisories.

The use of HIWAS (albeit a need to extend the mileage coverage) or other similar National systems should be considered for delivering in-flight space weather information.

3.2.3.2 En Route Flight Advisory Service

The purpose of EFAS, radio call “FLIGHT WATCH” (FW), is to provide en route aircraft with timely and pertinent weather data tailored to a specific altitude and route using the most current available sources of aviation meteorological information.

EFAS specialists tailor en route flight advisories to the phase of flight that begins after climb out and ends with descent to land. Current weather and terminal forecast at the airport of first intended landing and/or the alternate airport is provided on request. When conditions dictate, EFAS specialists provide information on weather for alternate routes and/or altitudes to assist the pilot in the avoidance of hazardous flight conditions.

The use of EFAS or other similar National services should be considered for delivering in-flight space weather information.

## 3.3 Space Weather Education and Training

Overall, the aviation industry does not understand space weather effects or their impacts on aviation operations. In addition, operators do not really understand the current space weather forecasts and information, and therefore, do not know how to make operational decisions based on the information. Even aviation meteorologists, while trained to interpret scientific data, are not educated about the specialized area of space weather.

With the development and incorporation of new space weather information into terrestrial weather briefings there will be a requirement to develop an education and training program to understand some of the basic science and the terminology. When it comes to HF communications, operators need to understand what are the usable frequencies. To understand navigation, they need to understand uncertainty in GPS. With respect to radiation, operators need to understand atmospheric ionizing radiation and how to interpret tools for monitoring and mitigating radiation health hazards to aircrew and passengers, and the effects upon avionics. Education and training will be required at all levels (e.g., dispatchers, aircrew, ATC, meteorologists).

While operators, agencies and unions have education and training programs already, most do not include space weather as a topic. Therefore, establishing the need for an education process remains a challenge. The materials need to be simple and standard.

The FAA and NOAA SWPC has recently been tasked by ICAO to write a space weather guidance material document for aviation that will be adopted by ICAO. This guidance material offers a first step towards a complete aviation space weather education and training curricula.

In order to generate the Education and Training, further work will be required to investigate exactly what aviation organizations, airlines, and unions want, and how the training should be delivered.

It is worth noting that consideration of, and dealing with space weather is now on the agenda of the WMO. ISES has also established dialogue with the WMO about how best the established ISES RWCs can utilise WMO channels to deliver standardised space weather information to users such as the aviation industry. ISES is currently working on a new website, http://www.spaceweather.org, that will provide space weather information and serve as a gateway to all websites on space weather. This service should be considered as a possible host for the aviation space weather education and training material adopted by WMO and ICAO.

# 4 Standardizing Aviation Space Weather Information

The need for new and improved space weather information and data is now very clear, and with the continued growth in air travel and the envisaged technological developments, the aviation community requires clarification on the information that is acceptable to be delivered and utilized for their operations. Similarly, space weather information and service providers need guidance on how to standardize the information for the aviation industry.

Similar to the previous section, understanding how terrestrial weather is standardized for aviation will help space weather providers with how to configure their information and services for delivery.

In order to standardize terrestrial weather aviation information, it is regulated by classification, type and source. It is recommended that the development and delivery of space weather information and services should pay heed to this standardization.

This section considers:

* standardization of space weather information and guidance in their use;
* descriptions of the types of space weather information;
* categorization of the sources of space Weather information.

## 4.1 Standardization of Space Weather Information

Like terrestrial aviation weather, space weather information should be classified as *primary* space weather information, and *supplementary* space weather information.

## 4.1.1 Primary Space Weather Information

Primary space weather information is an aviation space weather product that meets all of the regulatory requirements and safety needs for use in making space weather-related dispatch and flight decisions.

## 4.1.2 Supplementary Space Weather Information

Supplementary space weather information is an aviation space weather product that may be used for enhanced situational awareness. Supplementary space weather information must only be used in conjunction with primary space weather information. In addition, the use of supplementary space weather information may be restricted through limitations described in the product label.

## 4.2 Types of Aviation Space Weather Information

The following types of space weather information are required for aircraft operations: observations, analyses and forecasts.

## 4.2.1 Observations

Observations are classified as raw data collected by sensor(s). At this time the document can only really include satellite and ground monitors. Further identification of exact sensors to be used is required: whether by agency, National or International asset.

Collating airborne data from research projects can provide some additional temporary data, but only when airborne instruments become more widely and/or permanently installed can this source of observations be included. However it is recommended that the formatting and delivery of these observations should be considered, e.g., Pilot Reports (PIREPs).

## 4.2.2 Analysis

Analyses of space weather information are enhanced products and/or interpretation of observed space weather data.

## 4.2.3 Forecasts

Forecasts are the predictions of the development and/or variations of the space weather environment within the volume from Sun to Ground based upon observations of specific event or phenomena and/or mathematical modeling.

Like terrestrial weather in-flight advisories (i.e., Significant Meteorological Information [SIGMET]), in-flight space weather advisories will be needed and will be considered forecast space weather information products.

## 4.3 Categorizing Space Weather Aviation Sources

It is envisaged that categorization of space weather aviation sources could follow that laid down for terrestrial weather, and should take place at ICAO and WMO level through the work now being undertaken by the FAA (for ICAO) and by ISES (with WMO).

Thereafter, co-ordination by ISES through its RWCs would enable National aviation regulatory agencies to define and categorize the sources.

For example, in the US, NOAA SWPC (one of the ISES RWCs) now operates from within the authority of the National Weather Service (NWS). Therefore, within the US the FAA could categorize the approved space weather aviation sources as Federal Government and Commercial Space Weather Information Providers. Para’s 4.3.1 and 4.3.2 provide further details of how this categorization of space weather sources in the US may be accomplished. Other approved terrestrial weather sources do exist and should be investigated.

## 4.3.1 Federal Government

The SWPC collects space weather observations. The SWPC analyzes the observations, and produces forecasts, including some advisories applicable to aviation. The FAA and NWS should then disseminate the observations, analyses, and forecast products through a variety of systems. The federal government should be the only approval authority for sources of primary space weather observations.

Commercial space weather information providers could be contracted by the FAA to provide space weather observations and would be included in the federal government category of approved sources by virtue of maintaining required technical and quality assurance standards under FAA and NWS oversight.

## 4.3.2 Commercial Space Weather Information Providers

Aviation space weather information and services are still at the concept stage and so commercial space weather providers are likely to be a major source of space weather products for the aviation community. They are likely to produce new proprietary space weather products based upon FAA and NWS guidelines and not on already established products that they repackage.

Commercial providers who wish to produce forecasts, analyses, and other proprietary space weather products should provide, on request to operators and pilots, appropriate descriptions of services and provider disclosure. This should include, but is not limited to:

* the type of space weather product (e.g., current or forecast space weather);
* the currency of the product (i.e., product issue and valid times);
* the relevance of the product.

5 References

Cannon, P. S., M.J. Angling, J.A.T. Fieaton, N.C. Rogers, A.K. Shukla, 2004: “The Effects of Space Weather on Radio Systems,” *Proceedings of the NATO Advanced Research Workshop on Effects of Space Weather on Technology Infrastructure*, Rhodes, Greece 25-29 March 2003, Kluwer Vol II/176, pp. 185-201, 2004.

Cerruti, Alessandro P.; Kintner, Paul M.; Gary, Dale E.; Lanzerotti, Louis J.; de Paula, Eurico R.; Vo, Hien B., 2006: Observed solar radio burst effects on GPS/Wide Area Augmentation System carrier-to-noise ratio, *Space Weather,*Vol. 4, No. 10, S10006, 10.1029/2006SW000254.

Council Directive 96/29/EURATOM of 13 May 1996: “Laying down basic safety standards for protection of the health of workers and the general public against the dangers arising from ionising radiation.” Official Journal of the European Communities, 39, L159. 29 June 1996.

Dyer, C.S., F. Lei, P.Truscott, 2006: “Solar Particle Events in the QinetiQ Atmospheric Radiation Model,” Paper presented at RADECS 2006 and accepted for publication in IEEE Transactions on Nuclear Science

Dyer, C.S., F. Lei, S. N. Clucas, D.F. Smart, M. A. Shea, 2003: “Solar Particle Enhancements of Single Event Effect Rates at Aircraft Altitudes,” *IEEE Transactions on Nuclear Science*, Vol. 50, No. 6, pp. 2038-2045, December 2003.

FAA, 2004: Aerospace Weather Policy and Standards Staff (ARS-20), “Users’ needs analysis, space weather draft report,” 15 April 2004.

Heavner, M.J., D.D. Sentman, D.R. Moudry, E.M. Wescott, C.L. Siefring, J.S. Morrill, E.J. Bucsela, 2000: “Sprites, Blue Jets, and Elves: Optical Evidence of Energy Transport Across the Stratopause”, AGU Monograph 123 *Atmospheric Science Across the Stratopause*, p 69-82.

Horne, R.B., 2001: “Space Weather Parameters Required by the Users”, ESA Space Weather Programme Study – Alcatel Consortium WP1300.

Jones, B., 2004: “Space Weather Effects on Aircraft Operations,” Proceedings of the NATO Advanced Research Workshop on Effects of Space Weather on Technology Infrastructure, Rhodes, Greece 25-29 March 2003, Kluwer Vol II/176, pp. 215-234, 2004.

Jones, B., 2004: “Space Weather - Operational & Business Impacts,” Airline Space Weather Workshop Report, NOAA SEC, Boulder, CO 23-24 February 2004, <http://www.solarmetrics.com>

Klobuchar, J.A., J.M. Kunches, and A.J. VanDierendonck, 1999: “Eye on the Ionosphere: Potential Solar Radio Burst Effects on GPs Signal to Noise, *GPS Solutions*, Vol. 3, No. 2, fall 1999, P. 69.

NOAA, 2004: Service Assessment: Intense Space Weather Storms, October 19-November 07, 2003, April 2004. Washington, D.C.: U.S. Department of Commerce.

Normand, E., 1996: “Single event upset at ground level,” IEEE *Trans. on Nucl. Sci*, 43, 6, pp 2742-2750.

OFCM, 2000: The National Space Weather Program. The Implementation Plan: 2nd Edition, July 2000. Committee for Space Weather, Office of the Federal Coordinator for Meteorological Services and Supporting Research, Washington, D.C.

OFCM, 2006: Report of the Assessment Committee for the National Space Weather Program, June 2006, Office of the Federal Coordinator for Meteorological Services and Supporting Research, Washington, D.C.

Olsen, J., P. E. Becher, P. B. Fynbo, P. Raaby, J. Schultz, 1993: “Neutron-induced single event upsets in static RAMs observed at 10 km flight altitude*,” IEEE Trans. on Nucl. Sci.,* 40, 2, pp 74-77.

Taber, A. and E. Normand, 1993: “Single event upset in avionics*,” IEEE Trans. on Nucl. Sci*., 40, 2, pp 120-125.

# 6 Appendix A: Acronyms

ACE Advanced Composition Explorer

ADDS Aviation Digital Data Service

AMS American Meteorological Society

APV Approach with Vertical Guidance

ATC Air Traffic Control

CAMI Civil Aerospace Medical Institute

COMET Cooperative Program for Operational Meteorology, Education, and Training

CME Coronal Mass Ejection

CPDLC Controller-Pilot Data Link Communications

CPWG Cross Polar Working Group

DOD Department of Defense

DOT Department of Transportation

ELV Expendable Launch Vehicles

ESA European Space Agency

EU European Union

EUV Extreme Ultra Violet

FAA Federal Aviation Administration

FAGS Federations of Astronomical and Geophysical Data Analysis Services

FAR Federal Aviation Regulation

FIR Flight Information Regions

FSS Flight Service Stations

GCR Galactic Cosmic Ray

GNSS Global Navigation Satellite System

GOES Geostationary Operational Environmental Satellite

GPS Global Positioning System

HF High Frequency

IATA International Air Transport Association

IAU International Astronomical Union

ICAO International Civil Aviation Organization

ICRP International Commission for Radiobiological Protection

IEC International Electrotechnical Commission

IEEE Institute of Electrical and Electronics Engineers

IFALPA International Federation of Air Line Pilots’ Association

IPT Integrated Product Team

ISES International Space Environment Service

ISO International Organization for Standards

IUGG International Union of Geodesy and Geophysics

JPDO Joint Planning and Development Office

LAAS Local Area Augmentation System (LAAS)

MBU Multiple Bit Upsets

MWO Meteorological Watch Office

NAS National Airspace System

NASA National Aeronautics and Space Administration

NextGen Next Generation Air Transportation System

NOAA National Oceanic and Atmospheric Administration

NOTAM Notice to Air Men

NPOESS National Polar-orbiting Operational Environmental Satellite System

NRCan Natural Resources Canada

NSF National Science Foundation

NSWP National Space Weather Program

NWS National Weather Service

OFCM Office of the Federal Coordinator for Meteorology

OPM Office of Personnel Management

OPSPEC Operational Specification

PCA Polar Cap Absorption

PEA Post-Event Analysis

POES Polar-orbiting Operational Environmental Satellite

QIPC Qualified Internet Communications Provider

RAM Random Access Memory

RLV Reusable Launch Vehicles

RWC Regional Warning Centers

SARP Standards and Recommended Practices

SEC Space Environment Center

SEE Single Event Effects

SEP Solar Energetic Particles

SESAR Single European Sky ATM Research

SEU Single Event Upsets

SIGMET Significant Meteorological Information

SPE Solar Proton Events, Solar Particle Event

SRAM Static Random Access Memory

Sv Sieverts

SWAP Severe Weather Avoidance Plan

UCAR University Corporation for Atmospheric Research

UHF Ultra High Frequency

ULR Ultra Long Range

UN United Nations

UNA User Needs Analysis

URSI International Union of Radio Science

USAF United States Air Force

VAAC Volcanic Ash Advisory Center

VHF Very High Frequency

WAAS Wide Area Augmentation System

WMO World Meteorological Organization

WMSCR Weather Message Switch Center Replacement

# 7 Appendix B: Action Items and Issues

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| --- | --- | --- | --- | --- |
| **Action Item No.** | **Reference** | **Issue** | **Description** | **Service Need** |
| AI-01 | Para 2.2.1.1.4 | The designation of the aviation global airspace and how it should best be organized in order to support the delivery of space weather information to the aviation users requires further discussion | The global airspace can be delineated for space weather forecasts, observations and information in many different ways to suit the needs of the aviation industry. There may be some similarities that can be used from the way terrestrial weather is disseminated globally, but the physical properties of certain space weather phenomena occur across much larger areas, sometimes encompassing multiple Flight Information Regions (FIRs) with varying operations and Air Traffic Control procedures | Input required from the ATM representatives of the CPWG, ISES, WMO and VAACs. |
| AI-02 | Para 2.2.1.1.4 | The possibility of translating space weather information between geomagnetic and geographic co-ordinates needs to be addressed | Unlike terrestrial weather, space weather information uses geomagnetic co-ordinates. | Input required from ISES, WMO. |
| AI-03 | Para 2.2.6 | The need for changes to the NOAA SWPC Space Weather Scale for Solar Radiation Storms | The Biological effects, and S1 – S5 scales, are no longer considered applicable to passengers and crew in aircraft, as the physical measure is based upon particle energies too low to have any significant effect. | a. SWPC explore a new scale or system for passenger and crew exposure in aircraft based upon particle energies ≥100MeV  b. SWPC discuss with airlines how to interpret current space weather information with regard to human exposure from higher energy particles and space weather activity |
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# 8 Appendix C: Space Weather Impacts on Aviation Operations

## 8.1 Space Weather Environment

Space weather refers to 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 endanger human life or health (OFCM, 2000).

The space weather events that concern commercial air and space operations most are those that disrupt the operational systems and those that increase the radiation environment. Galactic Cosmic Rays (GCR), Coronal Mass Ejections (CME), Solar Particle (or Proton) Events (SPEs), solar flare radio blackouts, solar radiation storms, geomagnetic storms, and ionospheric storms are some of the terms that will become familiar to the aviation industry (see Box 8-1).

Space Weather Impacts on Aviation

**Solar Flare Radio Blackouts**: disturbances of the ionosphere caused by X-ray emissions from the Sun. HF radio degradation or blackouts are possible at middle and low latitudes.

**Solar Radiation Storms**: elevated levels of radiation that occur when the numbers of energetic particles increase. Typical effects from solar radiation storms include degradation of satellite tracking and power systems, radiation hazards to humans in flight at high altitudes or high latitudes. HF radio blackouts at high latitudes and induced positional errors to GPS are also possible.

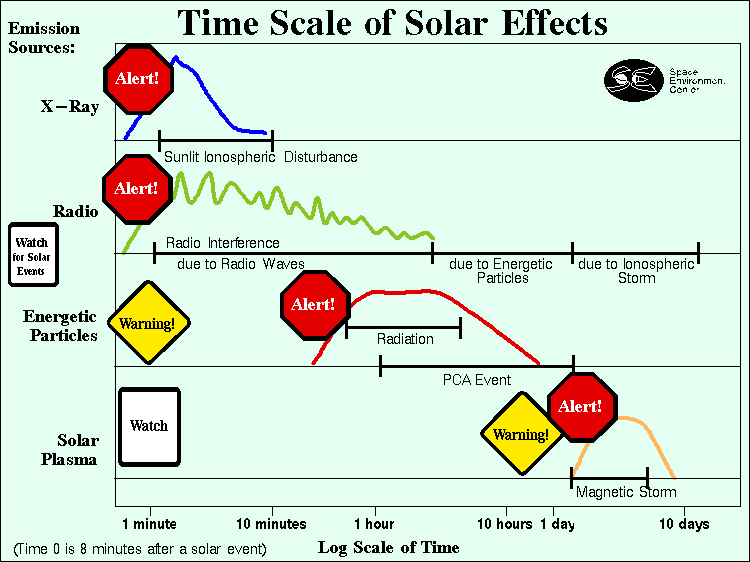
**Geomagnetic Storms**: disturbances in the geomagnetic field caused by gusts in the solar wind that blows by Earth. Typical effects from geomagnetic storms include degradation of HF radio transmissions, satellite navigation degradation, and disruption of low frequency radio navigation systems. Geomagnetic storms can also disrupt electrical power grids and ATC facilities and other national air space components are susceptible to these power outages. Geomagnetic storms also weaken the ability of the Earth’s magnetic field to deflect incoming charged particles.

**Box 8-1. Summary of space weather impacts on aviation.**

Cosmic radiation is the collective term for the radiation which comes from the Sun (the solar component, i.e., SPEs) and from exploding stars from the galaxies of the Universe (the galactic component or GCRs). These high-energy cosmic rays collide with the upper atmosphere, where they produce a cascade of secondary particles that shower down through the atmosphere to the Earth’s surface. It is the highly ionizing GCRs and secondary particles that are the primary source of the cosmic radiation hazard to humans at aircraft altitudes and can cause Single Event Effects (SEE) in aircraft avionics. GCR numbers vary with the approximate 11 year solar activity cycle, such that during solar maximum (associated with increasing sunspot numbers) the GCR flux entering the solar system is reduced by about 40%. During solar minimum, the opposite occurs with GCR numbers reaching their maximum intensity.

Solar flares with lifetimes ranging from tens of seconds to hours, release X-ray, ultraviolet, and radio emissions, producing ionospheric disturbances in the sunlit hemisphere with durations from minutes to hours. Some solar flares can release very energetic particles (primarily protons), which can arrive in the Earth’s atmosphere within 30 minutes. The Earth’s magnetic field does offer some protection, but these particles can spiral down the field lines, entering the upper atmosphere in the polar regions where they produce additional ionization in the ionosphere and increase the radiation at aircraft altitudes. A consequence of a geomagnetic storm, however, is that it weakens the amount of protection provided by the Earth’s magnetic field, thus increasing the level of ionizing radiation at aircraft altitudes.

The explosive release of CMEs from the Sun’s outer atmosphere over the course of several hours can also rapidly shower the Earth with energetic particles (radiation storm). Since the solar wind varies over time scales as short as seconds, the boundary between interplanetary space and the Earth’s magnetosphere is extremely dynamic. One to four days after a solar disturbance, a plasma cloud reaches the Earth, pummeling the magnetosphere and causing a geomagnetic storm. During these storms, very large electrical currents of up to a million amperes can flow through the ionosphere and magnetosphere, which can change the direction of the Earth’s magnetic field at the surface by up to 1 or 2 degrees, mainly in the auroral regions although these effects can extend to mid-latitudes. These variations in particle fluences and magnetic fields can impact the atmospheric radiation levels as well as severely disrupt radio communications.



**Figure 8-1. The time scales of solar effects (source: NOAA SWPC). Eight minutes after a flare and/or a CME erupts from the Sun, the first blast of Extreme Ultraviolet (EUV) and X-ray light increases the ionospheric density, which can impact HF communication loss. 10 minutes to several hours later, energetic particles arrive. One to four days later, the CME passes and energizes the magnetosphere and ionosphere, affecting navigation systems and radio communications.**

## 8.2 Communications

Polar flights departing from North America use Very High Frequency (VHF) (30–300 MHz) communication with NAVCANADA, the Canadian ATC. Operators will communicate initially with the Edmonton control center and then transition to Arctic Radio, the agency responsible for relaying messages between flight crew and NAVCANADA. While the flight’s initial communication with Arctic Radio is generally on VHF, pilots will eventually switch to HF (3–30 MHz). SATCOM is considered a backup during polar flights, but is rarely available above 82 degrees latitude.

Many communication systems utilize the ionosphere to reflect radio signals over long distances. However, if there is an ionospheric storm, HF or low VHF radio communication at all latitudes can be affected (Cannon et al, 2003). Some radio frequencies are absorbed, while others are reflected, leading to rapidly fluctuating signals and unexpected propagation paths. Solar flare ultraviolet and X-ray bursts, solar energetic particles, or geomagnetic storms can all bring on these conditions. If the effects become especially strong, it can cause a total communications blackout. SPEs produce a particular type of disturbance called Polar Cap Absorption (PCA) that can last for many days. When very energetic particles enter the atmosphere over the polar regions, the enhanced ionization produced at these low ionospheric altitudes (50–100 km) is particularly effective in absorbing HF radio signals and can render HF communications impossible throughout the polar regions. Airlines have diverted flights due to HF communication loss, which have caused en route time penalties of up to 180 minutes.

Other airspace regions of civil operations also rely heavily on HF communications. The North Atlantic and Pacific Ocean regions use HF for aircraft position reporting to maintain separation while outside of ATC radar coverage. Even relatively minor space weather disturbances can seriously disrupt the HF signal causing significant impact on these oceanic region procedures. While the newest aircraft can make use of the latest automated satellite reporting system, reducing their reliance upon HF in such regions, ATC can only communicate with older aircraft via HF to ensure that safe separation is maintained. Over vast areas of the South American and African continents, and the Indian Ocean, HF is the only means of communication. Furthermore, in some parts of central Africa HF is the only way of communication between neighbouring ATC units. To compensate for the poor or non existent ATC surveillance over most of Africa, the International Air Transport Association (IATA) introduced Inflight Broadcast Procedures (IFBP) on air-to-air frequencies. Pilots transmit their flight level, direction of flight, next position and time over that position on VHF 126.9 MHz. Should a conflict arise ahead, the crews of the conflicting aircrafts will decide what avoidance action to take. A disruption of these air-to-air frequencies in conjunction with HF loss can have an immediate effect on aviation safety. Improving information and awareness of anticipated communication outages will help to maintain safety margins.

Within normal radar coverage, civil aircraft operations use VHF frequencies. Although less prone to interference, VHF signals can be lost in the noise produced by solar flares: a point not generally considered when investigating temporary losses of communication between aircraft and ATC. Action focuses primarily on aircraft equipment serviceability, with the majority resulting in a “no fault found.” Such transient losses of communication could result in aircraft separation minima being eroded as ATC avoidance transmissions are missed, or within the military sphere, a friendly aircraft is engaged as hostile due to lack of response. Ensuring robust communications will become more important for future civil and military, air and space operations within the network‑centric airspace management envisaged by NextGen.

## 8.3 Satellite Navigation

The aviation industry is also concerned about space weather effects on the future Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS): Global Positioning Satellite (GPS)–based navigation and landing systems that will provide precision guidance to aircraft in cruise and at thousands of airports and airstrips. GNSS, the collective term describing all global navigation systems (e.g., GPS [USA], GLONASS [Russia], Galileo [Europe], and Compass [China]), is expected to provide extensive satellite-based navigation to aviation users of the future. During a geomagnetic storm, the bulk electron content of the ionosphere changes rapidly and can introduce horizontal and vertical errors of several tens of meters. GNSS operates by transmitting radio waves from satellites to the ground, aircraft, or other satellites and therefore is sensitive to ionospheric changes that occur during geomagnetic storms.

Future airspace management is reliant upon the increasing use of GNSS for navigating aircraft so that the separation between aircraft can be reduced, to position the aircraft on approach, and for landing in all weather conditions. However, the accuracy of the satellite signals, which must pass through the ionosphere, is affected by ionospheric variations due to solar and geomagnetic activity. Dual-frequency satellite receivers actually measure the effect of the ionosphere on the satellite signals and can better adjust to, but not eradicate, these difficult circumstances. This is accomplished by using a network of fixed ground‑based GPS receivers, separated by a few hundred km, to derive a map of the ionosphere. The map is then transmitted to the aircraft so that the GPS receiver on board can make an accurate ionospheric correction.

The WAAS was commissioned in 2003 for use in all phases of air navigation, which through the implementation of GNSS Approach with Vertical Guidance (APV), to provide users with the capability to fly approaches with vertical guidance throughout the U.S. national air space to 250 feet above a runway, even in conditions of poor visibility.

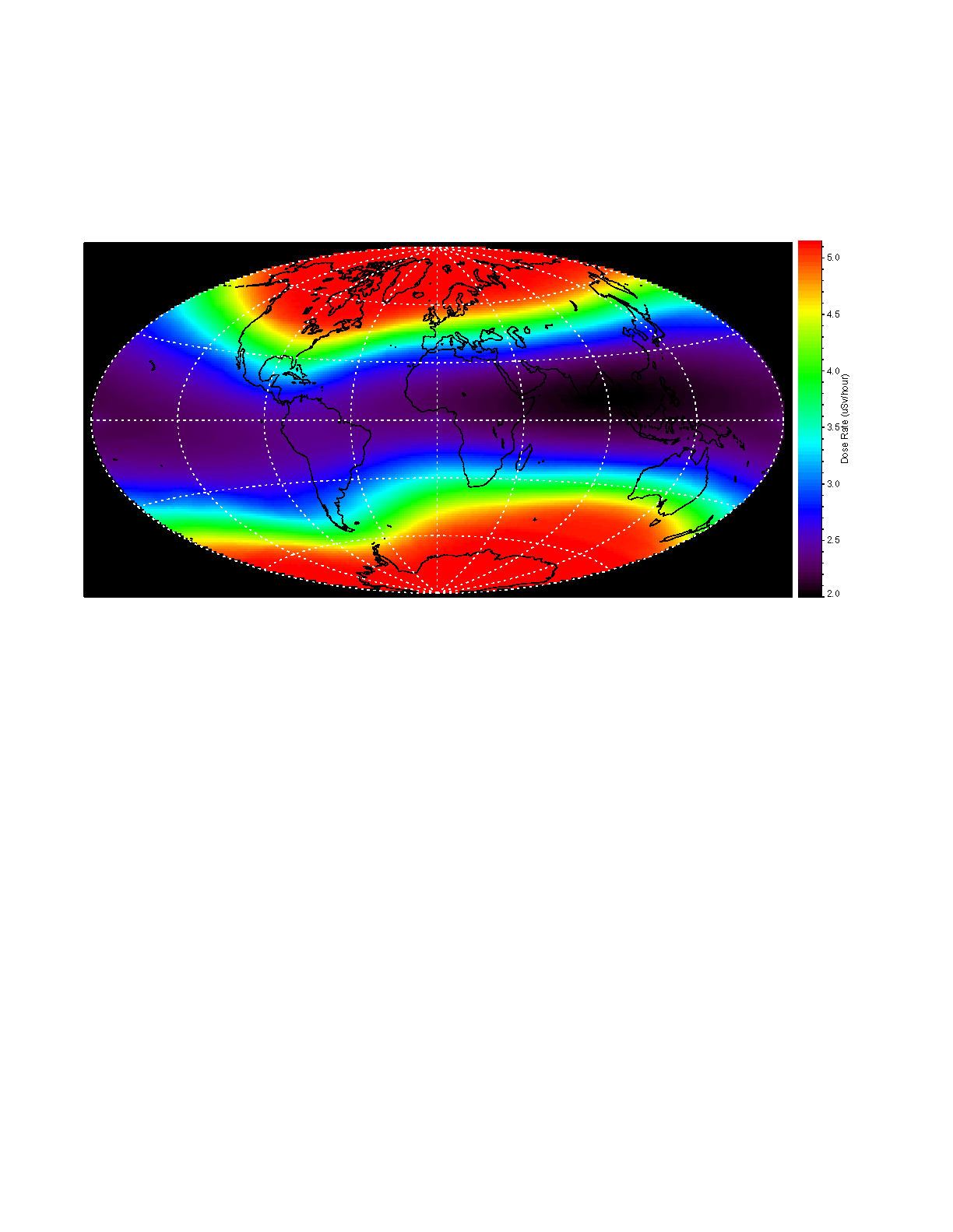
In the WAAS system, the standard GPS service is augmented with corrections for time, the GPS satellite orbits, and the ionosphere. These augmentations enable the WAAS system to meet the very stringent aviation requirements for accuracy, availability, and integrity. Quarterly performance reports have shown that the WAAS system generally meets or exceeds these requirements. However, the performance reports also verify that one of the greatest challenges for WAAS is maintaining continuous APV availability during extreme geomagnetic storm events. During the extremely disturbed days of October 29 and 30, and November 20, 2003 the APV service was unavailable over the entire contiguous U.S. (CONUS) region for periods of approximately 15 and 10 hours, respectively (OFCM, 2006).

On a smaller scale, irregularities in the density of the ionosphere that produce scintillations occur in varying amounts, depending on latitude. For example, the equatorial region, (the latitude zone that spans 15–20° either side of the magnetic equator) is the site of some of the greatest ionospheric irregularities, even when magnetic storms do not occur. Seemingly unpredictable episodes of density enhancements in the upper ionosphere can occur there in the evening hours and can cause radio waves to be misdirected. These scintillations make GPS operations difficult.

Until recently, the ionosphere has been considered as the sole source of space weather effects on GNSS signals, systems, and navigation accuracy. New research (Klobuchar et al, 1999; Cerruti et al, 2006) now suggests there is a different class of space weather effects on these signals: solar radio bursts. Solar radio bursts affect the GNSS system by attenuating the carrier-to-noise ratio, thereby degrading the received signals. These bursts can have durations from tens of seconds to a few hours.

## 8.4 Radiation Exposure to Humans

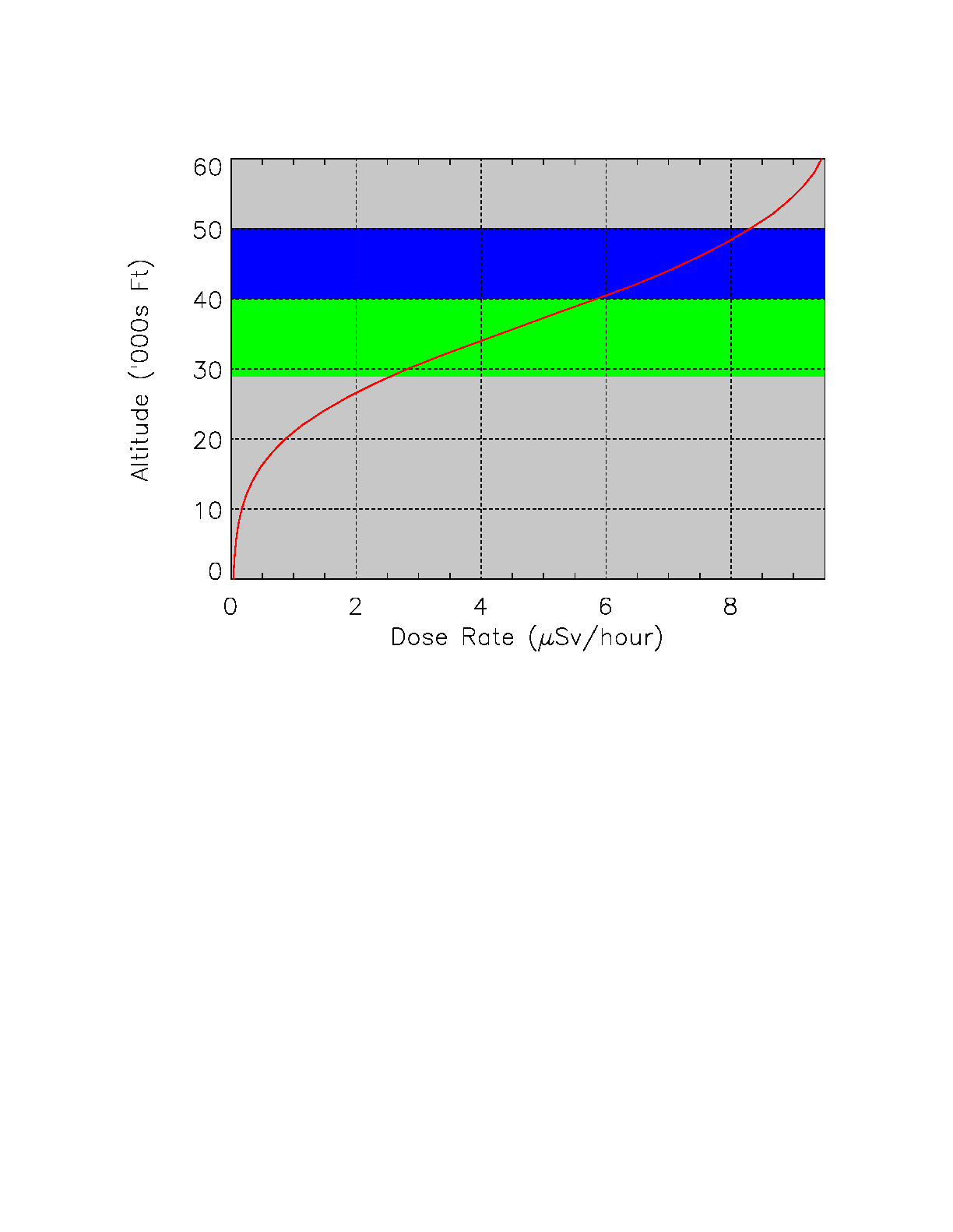
The principal space weather hazard to humans is exposure to cosmic radiation, which is caused primarily by GCRs. These very energetic GCRs start interacting with the atmosphere at around 130,000 ft causing secondary particles to shower down into the denser atmosphere below. This “particle shower,” and the corresponding level of radiation dose, reach a maximum intensity at around 66,000ft (~20 km) and then slowly decrease with decreasing altitude down to sea level. The dose rates also increase with increasing latitude until reaching about 50 degrees, where upon it becomes almost constant (see Figure 2 and 3).



**Figure 8-2. Projected global dose rate at 35,000 ft (Image courtesy SolarMetrics Limited).**

The dose rate at an altitude of 39,000 ft (12 km) in mid-temperate latitudes (temperate zones are 23.5° to 66.5° North and South) is typically up to about 6 microSieverts (µSv) per hour, but near the equator only about 3µSv/hr. (The Sievert [1 Sv=1 Joule/kg] is a measure of potential harm from ionizing radiation.) Typically, a London to Los Angeles flight in a commercial aircraft accumulates ~65µSv (6µSv/hr); however, the solar cycle can give ± 20% variations in dose from solar minimum to maximum.

**Figure 8-3*.* Change in dose rate due to cosmic radiation (GCR component) as a function of altitude and aircraft operational type (Image courtesy SolarMetrics Limited).**



**Future Air Transport**

**Business Jets, Airliners**

**Commercial Airliners**

**Commercial Airliners**

Besides the radiation from GCRs, of concern are those SPEs that increase the dose at aircraft altitudes. Most solar flares accelerate protons with energies up to 10’s of MeV (electron volt [eV]: a measurement unit for energy, equal to the energy an electron [or proton] would gain when accelerated by an electric voltage of 1 volt). There have been about 10 such events per year on average. However, only protons with energies in excess of 300MeV can produce increases at aircraft altitudes and on average there have been approximately three events per solar cycle with sufficient intensity and energies to produce significant radiation in the atmosphere. During the SPE of 1956 it has been estimated (Dyer et al, 2006) that the radiation dose received at 40,000ft (12km) on a transatlantic flight would have been approximately 10mSv. Such events are extremely rare (once every 100 years), but recent studies of smaller more typical events in September and October 1989 indicate 2mSv for a similar flight. Any increase in the radiation doses received from solar radiation storms cannot yet be predicted and will require retrospective additions following a post‑event analysis.

Monitoring occupational exposure to natural sources of ionizing radiation is currently included in the recommendations provided by the International Commission for Radiological Protection (ICRP). This includes exposure to the background cosmic radiation received while flying. Under present ICRP guidelines, the recommended dose limit for aircrew is a 5-year average dose of 20 milliSieverts (mSv) per year, but with no more than 50 mSv in any single year. For a pregnant crewmember, starting when she reports her pregnancy to management, her work schedule should be such that the equivalent dose to the child does not exceed 1 mSv during the remainder of the pregnancy, with no more than 0.5m Sv (FAA recommendation only) in any month. The Council of the European Union (EU) adopted Directive 96/29 Euratom on 13 May 1996. Article 42 of the Directive imposes requirements relating to the assessment and limitation of air crew members’ exposure to cosmic radiation and the provision of information on the effect of cosmic radiation. EU Member States were required to implement the Directive by 13 May 2000 through national legislation. However, in line with “best practice” radiation protection procedures, which is to keep all radiation exposures as low as reasonably achievable (ALARA principle), the EU has also adopted an “action level” of 6 mSv/yr, beyond which the EU registered operators must keep a record of an individuals’ exposure. Below 6 mSv/yr exposure monitoring is only a recommendation: actual implementation varies between EU Member States. Current flight profiles and annual flight hours generally make this a workable limit when monitored through record keeping, although it still makes aircrew the most highly exposed workforce beyond even nuclear power workers. In Japan, state regulations recommend that Japanese airlines have to try to keep their aircrews below 5mSv/yr, which is the dose limit for other occupationally exposed workers in Japan.

However, as future commercial aircraft are being designed for increased range (i.e., growth of polar-route traffic) or to utilize the available airspace at higher and higher altitudes, then significant increases in the doses are expected (8–10µSv/hr at 42,000 ft, 10–12µSv/hr at 51,000 ft). Quicker flights will reduce doses, but significant increases in cruising speeds will need to be achieved: the stillborn Sonic Cruiser flying at Mach 0.98, would have reduced flight times by 15–20%, but with envisaged operating altitudes up to 50,000 ft, the route doses would increase by 30–40%. There are two effects that contribute to increased dose at high altitudes. First, the number of secondary particles increases with altitude, reaching a maximum at approximately 20 km, as described above. Second, the secondary particle composition is quite different at higher altitudes: it becomes more and more dominated by multiply-charged ions, which have a greater potential to cause biological damage.

However, current medical research is inconclusive, so there is not enough evidence that a person can develop cancer as a result of cosmic radiation, since the total career dose is received in low doses per flight, and accumulated slowly over the length of a flying career. It is difficult through epidemiological studies to find causation of cancer due to cosmic radiation as other lifestyle risk factors exist. However, the Linear No Threshold (LNT) theory is accepted within the radiation protection community, i.e., every radiation exposure will have an effect on human health. This issue is a major concern for the aviation and sub-orbital space industries, and more accurate data and more extensive studies are needed to assist medical research of the long-term health effects.

## 8.5 Radiation Damage to Avionics

The electronic components of aircraft avionic systems are susceptible to damage from the highly ionizing interactions of cosmic rays, solar particles and the secondary particles generated in the atmosphere. As these components become increasingly smaller, and therefore more susceptible, then the risk of damage also increases. This can corrupt systems leading to erroneous commands. These soft errors are referred to as Single Event Upsets (SEU). Sometimes a single particle corrupts more than one bit to give Multiple Bit Upsets (MBU). Certain devices could be triggered into a state of high current drain, leading to burn-out and hardware failure; such effects are termed single-event latch-up or single-event burn-out. All these interactions of individual particles are referred to as Single Event Effects (SEE).

Data collected from satellites incorporating sensitive Random Access Memory (RAM) indicate chips have had upset rates from one per day at quiet times to several hundred per day during solar radiation storm events. In-flight aircraft measurements of SEU sensitivity in 4Mb Static RAM (SRAM) produced a rate of 1 upset per 200 flight hours, and agreed well with the expected upset rate variations due to changing latitude. Research (Dyer et al, 2003) has already shown that 100MB of modern RAM found in laptops may suffer upsets every 2 hrs at 40,000 ft, or as much as 1 upset/minute in 1GB of memory due to the 29 September 1989 SPE event. The aviation industry has already catalogued such events on equipment: auto-pilots tripping out and flight instrument units latching into built-in tests. This problem is expected to increase as more low-power, small feature size electronics are deployed in “more electric” aircraft.

## 8.6 Future Technologies

## 8.6.1 NextGen, SESAR, CARATS – Global ATM Harmonisation

The future of air transportation and air traffic management is being tackled through multi-agency projects around the globe. In the US, Next Generation Air Transportation System, or NextGen, will address critical safety and economic needs for civil aviation in future years, out to 2025, while fully integrating national defense and homeland security improvements. The equivalent in Europe is known as Single European Sky ATM Research (SESAR), and the Comprehensive Assessment and Restructure of the Air Traffic Services (CARATS), is the Japanese equivalent to NextGen.

These future systems require that aircraft will be able to use information technology in a more robust way, with enhanced capabilities in the cockpit, better navigation and landing capabilities, and far more comprehensive and accurate knowledge of weather and traffic conditions in real time. The Joint Planning and Development Office (JPDO), which manages NextGen, has a Weather Integrated Product Team that has developed an operational concept for a significantly improved and integrated weather component, known as the 4-Dimensional Weather Single Authoritative Source Data Cube (4-D Wx SAS). The JPDO already recognizes that space weather must be integrated into this system and are working with government, academia, and industry to make sure it is integrated into aviation operations.

All systems will also have to consider the interactions between the ionosphere and terrestrial weather. The ionosphere can exhibit irregular variations related to the dynamics of the underlying atmosphere. While this aspect of space weather may appear to have a non-solar origin, its effects are most pronounced when the upper-atmosphere winds or lower-ionosphere composition is enhanced by the energy inputs from the active Sun. In addition, optical phenomena called “red sprites” and “blue jets” have been observed (Heavner et al, 2000) at altitudes extending from the tops of strong thunderstorms (at around 15-km altitude) to the lower ionosphere (about 95-km altitude). Possibly related to these optical signatures, intense electromagnetic pulses (10,000 times stronger than lightning-related pulses) have been detected over thunderstorm regions by satellites. These observations suggest that there may be a stronger connection between global thunderstorm activity and the ionosphere and upper atmosphere than previously suspected. Interest in their effects will depend on the future use of this region of Earth-space.

## 8.6.1.1 Global Weather Picture

These User Service Needs as defined by the CPWG have not been written to meet the more demanding weather requirements of future global air transport systems, i.e., the 4-D Wx SAS, as the envisaged performance requirements address the observed and forecast weather information needed by decision makers in the year 2025.

Instead, these CPWG User Service Needs are designed to meet the current and near-future aviation space weather information needs from today onwards. However, it is deemed useful that some background information on the envisaged global ATM system requirements be provided in this document so that the users and operational decision makers can clearly see how, in the long-term, space weather information is to be integrated and harmonized into the future network-centric 4-D weather picture.

*The following précised information is taken directly from the latest draft (Version 0.2c, September 10, 2008) Preliminary Performance Requirements developed by the FAA Weather Performance Requirements Team.*

*1.0 BACKGROUND*

*NextGen is focusing on a new direction in aviation weather information capabilities to help stakeholders at all levels make better decisions during weather situations. Safe and efficient NextGen operations will be dependent on enhanced weather capabilities based on three major tenets:*

* *A common picture of the weather for all transportation decision makers and aviations system users*
* *Weather integrated directly into sophisticated decision support capabilities to assist decision makers*
* *Utilization of Internet-like information dissemination to realize flexible and cost-efficient access to all necessary weather information*

*At the core of the NextGen weather capability is the 4-D Wx Data Cube, which is defined as all unclassified weather information used directly and indirectly for making aviation decisions. It contains all relevant aviation weather information (e.g., observations, automated gridded products, models, climatological data, and human-produced forecasts from public and private sources) to create the common weather picture.*

*This common weather picture is the 4-D Wx Single Authoritative Source (SAS), which provides seamless, consistent, de-conflicted weather information. At full NextGen implementation, the 4-D Wx SAS for ATM represents the machine-readable, network-enabled, geo- and time-referenced weather information authorized for use by ATM for decision making. The 4-D Wx SAS facilitates the integration of weather information directly into operational decision support tools. The 4-D Wx SAS provides the answer to all ATM operations looking at the same weather attribute for a given place and time.*

## 8.6.2 Commercial Space Transportation

The SpaceShipOne (SS1) Flights of 2004 heralded a new age of commercial space travel. Clearly such a pioneering venture has many immediate risks associated with such flights, but there are longer-term risks as well. Radiation levels in the atmosphere are many times higher than they are on the ground, reaching a peak at around 80,000 feet. Above this level, dose rates fall to roughly half the peak value at an altitude of 600,000 feet before climbing again as the radiation belts are approached (~106 feet and beyond). Significantly, as altitude increases above 80,000 feet, there is a shift in the composition of the radiation as the lack of atmosphere means fewer neutrons are generated, but fewer protons are absorbed.

There is relatively little information regarding the space weather radiation levels between the upper levels of the stratosphere and the inner radiation belts, particularly at low latitudes, (known as Low Earth Orbit at Low Inclination, or LEOLI) in to which sub-orbital space flights will operate. Compared to other regions of space (i.e., ISS and Shuttle operations) LEOLI represents a comparatively safe environment; however, even for astronauts on sub-orbital trajectories this region is still a place harbouring significant risks, particularly during anomalous solar activity.

Geomagnetic storms and solar proton events are probably the two most significant hazards in terms of radiation exposure. Highly charged and energetic ions, or HZEs, are also important for all commercial space operations as their rigidity (ability to penetrate the geomagnetic field) is greater than protons (approximately double - they do have a shorter range for interacting with the atmosphere but then produce more secondaries at lower altitudes). Therefore, at altitudes greater than 60000 feet primary ions and secondary fragments are very significant for both human dose and SEE in electronics.

With little or no atmosphere to absorb the various particles and lower energy protons associated with solar particle events, radiation doses may increase significantly towards the millisievert-per-minute mark, and geomagnetic storms may weaken the Earth’s magnetic field sufficiently to bring the radiation belts close to a LEOLI flight’s apogee (witness the low latitude auroras associated with the October-November 2003 storms that were observed in Texas, Florida and New Mexico).

Such occurrences are not every day events, but at certain times during the solar cycle they become more frequent and/or severe in nature. Therefore as commercial space transportation operations are developed there should be a requirement for space operators to include a space weather monitoring element to any Mission Control facility.

It is also worth noting that in the UK (Air Navigation Order), due to the transient nature and variability of solar particle events, any aircraft capable of flying above 49,000 ft should carry an active radiation detector, which can monitor radiation levels in real-time, to detect any significant short-term variations during flight.

# 9 Appendix D: Glossary of Space Weather & Radiation

**Absorbed Dose** (D): this is a measure of how much energy a source of radiation deposits in tissue (literally *heating* the tissue, albeit by only millionths of a degree). Unfortunately it tells us nothing about how damaging that radiation is, and for this reason we need other quantities like dose equivalent and effective dose. Absorbed dose is usually quoted in grays, milligrays or micrograys.

**Absorption** (of radio waves): Absorption (is the process by which the energy of radio waves are converted into heat and electromagnetic (EM) noise through interactions between the radio wave, ionospheric electrons, and the neutral atmosphere.

**Action Level**: this is a reference level at which some action must be taken to stop a person’s exposure becoming too high. For example, the 6 millisievert level for air crew is an action level: any crew member exceeding this figure could be required to fly less exposed routes to bring their annual dose back below 6 millisieverts.

**Activity**: a measure of how rapidly a radioactive material is decaying. It is usually quoted in becquerels, kilobecquerels or megabecquerels.

**ALARA**: As Low As Reasonably Achievable. This is one of the governing principles of radiation protection. It encourages work practices that keep exposures to a minimum, even when those exposures are already well below the required dose limits. An example might be to manipulate a radioactive source with 50 cm tongs rather than 25 cm tongs, thereby reducing the worker’s exposure. Of course, using a remotely controlled robot would reduce the worker’s dose even further, but would probably cost hundreds of times more than a longer set of tongs (hence Reasonably Achievable). Unfortunately, due to the nature of air crew exposure to cosmic radiation, there is little than can be done to reduce exposures from their present levels.

**Alpha Particle** (α): one of the more common forms of particle radiation emitted from an unstable atomic nucleus. An alpha particle is actually an atomic nucleus in its own right, essentially being an ionised atom of the element helium.

**Ambient Dose Equivalent** (H\*(10)): this is one of several quantities used to assess the effects of radiation on people, and like the others it is usually quoted in sieverts, millisieverts or microsieverts. Most detectors used in radiation protection have been designed to measure ambient dose equivalent, as it is a simpler quantity to measure than effective dose.

**Amino Acid**: one of a number of special molecules that link together easily to make proteins and other biologically important structures. Four different amino acids are the ‘active ingredient’ in DNA: adenosine, cytosine, guanine and thymine (or A, C, G and T for short). A long sequence containing these four amino acids form a mini-instruction set called a gene. Although the amino acids can be linked in any order or combination on one of DNA’s two strands, the arrangement on the first strand fixes the arrangement on the second. Adenosine on Strand One requires cytosine on Strand Two (and vice versa), likewise with guanine and thymine.

Hence if Strand One contains the sequence ATGCAATGC, then Strand Two would have to be CGTACCGTA.

**Becquerel** (Bq): the unit of activity. One Becquerel is equivalent to one nuclear disintegration per second. N.B. one disintegration may produce more than one form of radiation, e.g. several gamma rays, neutrons and/or alpha particles.

**Charge**: an electrical property associated with most subatomic particles that cause them to either be attracted to or repelled from each other. It comes in two forms: positive charge and negative charge. Charges of the same type repel each other, whereas opposite charges attract each other. Electrons have a negative charge and protons have a positive charge.

**Chromosome**: a collection of genes strung together. There are 23 pairs of chromosomes in humans, the most famous of which are the X and Y chromosomes.

**CME**: see Coronal Mass Ejection.

**Coronal Mass Ejection**: CME. A pocket of plasma gas ejected from the Sun’s outer regions (the Corona), usually caused by the interaction of different sunspots. A CME follows a spiral track out from the Sun. A CME that then collides with the Earth causing significant increases in particle numbers in the atmosphere is known as a solar particle event (SPE), or sometimes a solar energetic particle event. If the particles within the plasma gas are energetic enough, they can cause ground level monitor count rates to increase, and therefore become reclassified as a ground level event.

**Cosmic Radiation**: CR. Highly energetic radiation, primarily protons, which enter the upper atmosphere, and collide with oxygen and nitrogen atoms. This generates a whole range of different types of radiation, including neutrons, gamma rays and electrons, which can penetrate down to aircraft altitudes. CR is usually divided into two categories: galactic cosmic radiation and solar cosmic radiation.

**CR**: see Cosmic Radiation.

**DNA** (Deoxyribonucleic acid): the molecule that makes up genes and chromosomes. DNA itself is made of a double-helix structure of amino acids, which is essentially two intertwined spirals. DNA holds the blueprint for the construction of an individual’s cells, and the implications of damage to a cell’s DNA are enormous. Fortunately the double-helix structure is actually very robust: damage to one strand of the double-helix can usually be repaired by referring to the undamaged strand. It is only when there is damage to both strands that that the DNA is unlikely to be properly repaired. Different types of radiation have different likelihoods of damaging one or both strands of DNA, which is why tissue is more sensitive to some sorts of radiation than others. N.B. DNA can be damaged in other ways, e.g. by chemicals, viruses, etc.

**Dose**: a measure of energy deposited in tissue by radiation. Confusingly, it is used as a short-hand for a number of different quantities including absorbed dose, ambient dose equivalent, personal dose equivalent and effective dose.

**Dose Limit**: a legal restriction on the level of exposure that a person can receive. In the UK, the annual dose limit for occupationally exposed workers is 20 millisieverts, for members of the public it is 1 millisievert. N.B. the figure of 6 millisieverts applied to air crew is an action level rather than a dose limit.

**D-region Absorption**: Most of the absorption of radio waves occur in the ionospheric *D* region (50 - 90 km altitude). Within this region the neutral density is relatively constant over time, so variations in the local electron density drive the total amount of absorption. The electron density is a function of many parameters and normally varies with local time, latitude, season, and over the solar cycle. These "natural" changes are predictable, and affect absorption only moderately at the lowest HF frequencies. Much more significant changes to the electron density, and therefore the absorption strength, are seen as a result of solar x-ray flares.

**Effective Dose** (E): this is the ‘legal quantity’ in radiation protection. It is actually a theoretical quantity, as it is based around a ‘standard person’. It takes account of the differing damage caused by different types of radiation to human tissue, and of the different sensitivities of different tissues to radiation in general. Like all the other quantities that measure the harm caused to people by radiation, effective dose is usually quoted in units of sieverts, millisieverts or microsieverts. The quantities ambient dose equivalent and personal dose equivalent were conceived as ways to measure this theoretical quantity.

**Electromagnetic Radiation**: little parcels of electric and magnetic fields that oscillate in strength. The frequency of that oscillation dictates how much energy the parcel contains. Examples of electromagnetic radiation (in order of increasing frequency) are: radar, microwaves, infrared radiation, visible light, ultraviolet radiation, x-rays and gamma rays.

**Electron**: one of the three types of particle that make up every atom in the universe (the others being the proton and the neutron). Electrons buzz around the central atomic nucleus in a number of layers or *shells*. Each electron carries one unit of negative charge. Electrons can be knocked free of their shells by interactions with x-rays and gamma rays, or by the passage of other charged particles such as protons or alpha particles. This process is called ionisation, and can lead to tissue damage.

**Energy**: the capacity for motion. If two identical objects are moving at different speeds, the faster of the two has more energy. This form of energy is probably the most familiar to us and is called *kinetic energy*. The hotter an object is, the more energy it contains. Although it may not be moving anywhere as a whole, the individual molecules that make up the object will be vibrating faster. Similarly with electromagnetic radiation it is the speed of the oscillations, which translates to the frequency of the radiation that determines how much energy is carried.

**Epidemiology**: the study of illnesses and rates of illnesses within a population by statistical analysis.

**Exposure**: strictly speaking, this is a measure of how much radiation energy is absorbed in air, but now also indicates that a person has been subjected to a dose of radiation, e.g. occupational exposure.

**Fallout**: as with any explosion (natural or otherwise), dust particles can be projected high into the atmosphere, carried for hundreds of miles and then settle again due to rainfall, etc. Fallout occurs when the source of the explosion was nuclear in nature. Currently, fallout accounts for only 0.2% of the total background radiation received each year.

**Forbush Decrease**: the increased solar activity that leads to increased solar wind and coronal mass ejections often have a positive benefit: the intense magnetic fields that accompany the particles in these events often provide extra magnetic shielding to the solar system, resulting in the levels of galactic cosmic radiation reaching the Earth being reduced. This phenomenon is known as a Forbush decrease.

**Galactic Cosmic Radiation** (GCR): highly energetic radiation thought to be created by supernovae, etc, where the outer layers of an exploding star are shock-accelerated to enormous speeds. This radiation, primarily protons, crosses the galaxy and possibly even between galaxies.

**Gamma Ray**: very high frequency electromagnetic radiation. Strictly speaking, gamma rays come from the reordering of disturbed protons and neutrons within the atomic nucleus; their emission is one method for a nucleus to shed unwanted energy.

**GCR**: see Galactic Cosmic Radiation.

**Gene**: a sequence of amino acids that act as a mini-instruction set for building new cells. Sequences of genes are gathered to form chromosomes.

**Geomagnetic Storm**: the Earth’s magnetic field shields us from the less-penetrating cosmic radiation by deflecting it away from the atmosphere. However, during solar particle events, the influx of large numbers of charged particles from the Sun can interfere with the Earth’s magnetic field, causing it to fluctuate and weaken in places, allowing more radiation to penetrate the atmosphere. Severe geomagnetic storms can actually cause compass needles to wobble!

**GLE**: see Ground Level Event.

**GLM**: see Ground Level Monitor.

**Ground Level Event** (GLE): a GLE is said to have occurred when a number of ground level monitors see a sudden increase in their counting rates of cosmic ray particles. It is indicative of increased dose rates at aircraft altitudes. Such events happen on average about once per year, but only very rarely will they manage even to double the in-flight radiation dose of a single journey.

**Ground Level Monitor** (GLM): these monitors usually detect neutrons created in the atmosphere by incoming cosmic radiation. There are many

monitoring stations around the world, at a wide range of latitudes and altitudes (depending on the location’s height above sea level!). The counting rates observed in these detectors can be related directly to the dose rates seen at aircraft altitudes, and follow the 11-year solar cycle.

**Helium**: the second lightest element in the universe. The helium nucleus consists of two protons and two neutrons tightly bound together: a very stable arrangement that is very difficult to break apart. Sometimes during radioactive decay, this combination of two protons and two neutrons is ejected from a larger unstable nucleus as it tries to shed excess energy. In this form it is known as an alpha-particle.

**HF**:

**Infrared Radiation**: medium-frequency electromagnetic radiation. Although infrared is *just* too weak to be detected as light by the retina of the eye, it can be detected by the skin as heat.

**Ionised Atom**: an atom with one or more electrons stripped from its electron shells. More frequently known as an ion, the missing electrons mean that the ionised atom is chemically active and it will react with another nearby molecule. If this happens in tissue, such as happens when ionising radiation passes through it, then important biological molecules can become damaged.

**Ionising Radiation**: radiation that carries enough energy to ionise any material it passes through, including tissue. Radar, microwaves and visible light do not carry enough energy to do this, but x-rays, gamma rays and most forms of particle radiation do. Ultraviolet light is an interesting case, as it is right on the borderline between ionising and non-ionising.

**Isotope**: a subset of an atomic element. Different isotopes contain the same number of protons in their atomic nucleus, but have different numbers of neutrons. Most are stable, but if they have too many or too few neutrons, they will be radioactive. Just how many, or just how few, will determine how unstable they are and what types of radiation they will emit.

**Medical Radiation**: radiation offers many benefits to the medical profession in both diagnostic and therapeutic areas. From chest x-rays (~20 microsieverts) to abdominal imaging (10 millisieverts), diagnostic procedures may appear to require high radiation doses, but the potential benefits of diagnosing serious illness outweighs the small chance of cancer induction from the procedure. Averaged over the whole population, medical radiation accounts for ~14% of the annual radiation background.

**MicroSievert** (µSv or uSv): one-millionth of a Sievert.

**Microwave**: a lower-frequency form of electromagnetic radiation that cannot be detected directly by people. However, specific frequencies of microwave match specific vibrations in water molecules, which means they are readily absorbed, transferring their energy to the water and heating it up. Not surprisingly, this is the method by which a microwave oven works.

**MilliSievert** (mSv): one-thousandth of a Sievert.

**Neutron**: one of the three particles that make up every atom in the universe (the other two being the electron and the proton). Neutrons are to be found in the atomic nucleus, along with the protons. Neutrons do not carry a charge, and it is this property that allows atomic nuclei containing many protons to remain stable by shielding the natural repulsion of protons. Curiously, neutrons not contained within an atomic nucleus are unstable, and will disintegrate within a few minutes. This is why galactic cosmic radiation is made primarily of protons!

**Nucleus**: the atomic nucleus holds the protons and neutrons found in atoms, around which the electrons buzz in layers or shells. If the number of protons and neutrons is not balanced, then the nucleus will be unstable and will eventually emit some form of radiation in order to achieve a balance. This natural process can be tapped to provide nuclear power (or nuclear weapons).

**Occupationally Exposed Worker**: this term simply acknowledges that somebody going about their normal job is exposed to levels of radiation above the normal background rates.

**PCA**: see Polar Cap Absorption.

**Plasma**. A gas of highly energised charged (i.e. ionized) particles. A plasma has no net charge but can often be magnetized.

**PMR**: see Proportional Mortality Ratio.

**POES Auroral Absorption**: Instruments on board the NOAA Polar-orbiting Operational Environmental Satellite (POES) continually monitor the power flux carried by the protons and electrons that produce aurora in the atmosphere. The SWPC processes the particle counts received into colour-coded plots. These plots provide an instant estimate of whether the current particle environment is more, or less, intense than usual, and this gives an indication of the likely absorption of HF radio waves.

**Polar Cap Absorption**: Solar energetic particles following Earth’s magnetic field lines can penetrate the upper atmosphere near the magnetic poles, resulting in ionization and creating a Polar Cap Absorption (PCA) event.

**Proportional Mortality Ratio** (PMR): this is a term used in epidemiology that compares the relative rate of deaths from a variety of causes in a given study group with the relative rates observed in a reference group (usually, but not always correctly (!), the general population), adjusted for the age distribution in the study group. This approach requires less information than other approaches, but the results can easily be distorted when a particular cause of death is abnormally high (or low).

**Proton**: one of the three particles that make up every atom in the universe (the other two being the electron and the neutron). Protons are to be found in the atomic nucleus, along with the neutrons. Protons carry a positive charge, and are therefore naturally repelled from each other, and can only form stable nuclei by the presence of a suitable number of neutrons. Protons are essentially an ionised form of hydrogen, and are the main constituent of galactic cosmic radiation.

**Radiation**: a method of energy transmission. Radiation is usually divided into ionising and non-ionising radiations; Particle radiations (e.g. protons, neutrons) are almost always ionising, but electromagnetic radiation can be both ionising (e.g. x-rays, gamma rays) and non-ionising (e.g. radar, microwaves).

**Radio Waves**:

**Radon**: a radioactive gas formed by the radioactive decay of uranium. On average, it is responsible for about 50% of the natural background radiation dose in the UK, although it can vary considerably. Levels can be particularly high in regions with a lot of granite-based rocks, e.g. Cornwall and Derbyshire.

**Sievert** (Sv): the unit that describes how dangerous ionising radiation is to human health. It takes into account how sensitive individual organs and tissues are, and how damaging different types of radiation are. A dose of 1 Sievert is believed to increase the risk of developing a fatal cancer by 4% (in the working population, 5% in the general public).

**SIR**: see Standardised Incidence Ratio.

**SMR**: see Standardised Mortality Ratio.

**Solar Activity**: a measure of how much radiation the Sun is emitting. This is closely linked to the number of sunspots that are present. Most of the radiation is in the form of the solar wind. Solar activity varies with an eleven year solar cycle.

**Solar Cosmic Radiation** (SCR): radiation emitted by the Sun rather than galactic cosmic radiation. The most common form of SCR is the solar wind, a continuous stream of low energy particles that has little direct impact on the Earth. However, occasionally, higher-energy particles can be emitted during coronal mass ejections, which can have serious implications for communications and air crew doses.

**Solar Cycle**: the Sun has an eleven year cycle of solar activity, governed by the fluctuations in the Sun’s internal magnetic fields. When the magnetic fields are strongest (known as solar maximum), more particles are emitted, mostly in the form of the solar wind. During this period, galactic cosmic radiation finds it most difficult to penetrate the solar system, and dose rates at aircraft altitudes are lower than average. Conversely, when the Sun’s magnetic fields are at their weakest (solar minimum), the solar wind is weaker and galactic cosmic radiation levels are higher than average. Solar flares and coronal mass ejections, triggered by magnetic interactions on the surface of the sun, tend to occur during the more active parts of the solar cycle.

**Solar Flare**: a burst of x-rays from the Sun, usually triggered by twisted magnetic fields in the Sun’s surface layers ‘snapping’ or unravelling. Solar flares themselves can have a number of impacts on the Earth; however, the same magnetic effects that cause solar flares often cause coronal mass ejections as well, which can also have an effect.

**Solar Maximum**: the peak of the Sun’s eleven year solar cycle. Curiously, solar maximum is the time when air crew doses tend to be at their lowest, as the increased solar wind helps shield the Earth from the effects of galactic cosmic radiation. It is generally believed that the larger solar particle events tend to occur near to solar maximum, although recent solar events, (October/November 2003, January 2005, etc) occurring nearer solar minimum, seem to challenge this notion.

**Solar Minimum**: The quietest time in the Sun’s eleven year solar cycle. Curiously, solar minimum is the time when air crew doses tend to be at their highest, as the reduced level of solar wind reduces the level of shielding protecting the Earth from galactic cosmic radiation.

**Solar Particle Event** (SPE): a coronal mass ejection (CME) or solar flare become known as a solar particle event if the particles en-route to Earth reach a high enough energy and quantity. This is most clearly signalled by massive increases in the count rates observed by specific satellites. Most particle events are not penetrating enough to raise dose rates at altitude to any significant degree; the exception to this being the ground level event, so-called as monitor stations on the Earth’s surface (ground level monitors) undergo a similar increase in counting rates to those observed in the satellites. Ground level events can, on occasion, increase dose rates at altitude significantly.

**Solar Wind**: is a flow of solar plasma permeated by the Sun’s magnetic field. This constant stream of low energy protons and electrons emitted from the surface of the Sun can actually help to shield the Earth from the more dangerous galactic cosmic radiation.

**Standardised Incidence Ratio** (SIR): this is an epidemiological term that compares the incidence rate of an illness or group of illnesses in a given study group with those observed in a reference group (usually, but not always correctly (!), the general population), adjusted for the age distribution in the study group.

**Standardised Mortality Ratio** (SMR): this is a term used in epidemiology that compares the rate of deaths from a variety of causes in a given study group with those observed in a reference group (usually, but not always correctly (!), the general population), adjusted for the age distribution in the study group.

**SPE**: see Solar Particle Event.

**Sunspot**: relatively cool areas on the surface of the Sun (hence they look darker), known for the intensity and complexity of their magnetic fields. Should the magnetic fields of two sunspots interact, large amounts of energy can be released in the form of solar flares or coronal mass ejections, or quite often both.

**Ultraviolet Radiation** (UV): reasonably high frequency electromagnetic radiation. UV carries just enough energy to cause some tissue damage, although it is not usually directly ionising.

**X-ray**: high frequency electromagnetic radiation. Strictly speaking, x-rays come from the reordering of disturbed electrons within the electron shells that surround the atomic nucleus.

# 10 Appendix E: NOAA SEC Space Weather Scales

**NOAA Space Weather Scale for Geomagnetic Storms**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **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 hrs** | | **Number of storm events when Kp level was met** |
| **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) |

\* The K-index used to generate these messages is derived in real-time from the [Boulder NOAA Magnetometer](http://sec.noaa.gov/rt_plots/bou_12h.html). The Boulder K-index, in most cases, approximates the Planetary Kp-index referenced in the NOAA Space Weather Scales. The Planetary Kp-index is not available in real-time.

\*\* For specific locations around the globe, use geomagnetic latitude to determine likely sightings.

**NOAA Space Weather Scale for Solar Radiation Storms**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category** | | **Effect** | **Physical measure** | **Average Freq. (1 cycle=11 yrs)** |
| **Scale** | **Descriptor** | **Duration of event will influence severity of effects** |  |  |
| **Solar Radiation Storms** | | | **Flux level of >= 10 MeV particles (ions)\*** | **Number of events when flux level was met (number of storm days)** |
| **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. | 105 | 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. | 104 | 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. | 103 | 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:** small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected. | 102 | 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.

**NOAA Space Weather Scale for Radio Blackouts**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category** | | **Effect** | **Physical measure** | **Average Freq. (1 cycle=11 yrs)** |
| **Scale** | **Descriptor** | **Duration of event will influence severity of effects** |  |  |
| **Radio Blackouts** | | | **GOES X-ray peak brightness by class and by flux\*** | **Number of events when flux level was met** |
| **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 (2 x 10-3) | Less 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 (5 x 10-5) | 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.

# 11 Appendix F: Radiation Legislation and Guidance

Legislation, based upon the International Commission on Radiological Protection (ICRP) standards, for the protection of air crew and passengers from ionizing radiation has been implemented in many ICAO member Countries, using various methodologies. Some examples of the legislation and guidance material is provided below as an aide memoir to understanding what the industry user requirements need to address on a global scale.

## 11.1 Legislation

## 11.1.1 EU Directive

EU Council Directive 96/29/EURATOM of 13 May 1996 *laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation*.

The relevant sections applicable to air crews and passengers in aircraft are:

**Article 42: Protection of air crew**

Each Member State shall make arrangements for undertakings operating aircraft to take account of exposure to cosmic radiation of air crew who are liable to be subject to exposure to more than 1 mSv per year. The undertakings shall take appropriate measures, in particular:

* to assess the exposure of the crew concerned,
* to take into account the assessed exposure when organizing working schedules with a view to reducing the doses of highly exposed aircrew,
* to inform the workers concerned of the health risks their work involves,
* to apply Article 10 to female air crew.

Where,

**Article 10: Special protection during pregnancy and breastfeeding**

1. As soon as a pregnant woman informs the undertaking, in accordance with national legislation and/or national practice, of her condition, the protection of the child to be born shall be comparable with that provided for members of the public. The conditions for the pregnant woman in the context of her employment shall therefore be such that the equivalent dose to the child to be born will be as low as reasonably achievable and that it will be unlikely that this dose will exceed 1 mSv during at least the remainder of the pregnancy.

2. As soon as a nursing woman informs the undertaking of her condition she shall not be employed in work involving a significant risk of bodily radioactive contamination.

## 11.1.2 EU OPS

EU OPS refers to European Community (EU) regulations specifying minimum safety and related procedures for commercial passenger and cargo fixed-wing aviation. The legislation is known officially as "COMMISSION REGULATION (EC) No 859/2008 of 20 August 2008 amending Council Regulation (EEC) No 3922/91 as regards common technical requirements and administrative procedures applicable to commercial transportation by aeroplane".

The references applicable to air crews and passengers in aircraft are:

***SUBPART D: OPERATIONAL PROCEDURES, OPS 1.390 Cosmic radiation (L 254/45)***

(a) An operator shall take account of the in-flight exposure to cosmic radiation of all crew members while on duty (including positioning) and shall take the following measures for those crew liable to be subject to exposure of more than 1 mSv per year:

1. assess their exposure;

2. take into account the assessed exposure when organising working schedules with a view to reduce the doses of highly exposed crew members;

3. inform the crew members concerned of the health risks their work involves;

4. ensure that the working schedules for female crew members, once they have notified the operator that they are pregnant, keep the equivalent dose to the foetus as low as can reasonably be achieved and in any case ensure that the dose does not exceed 1 mSv for the remainder of the pregnancy;

5. ensure that individual records are kept for those crew members who are liable to high exposure. These exposures are to be notified to the individual on an annual basis, and also upon leaving the operator.

(b) 1. an operator shall not operate an aeroplane above 15 000 m (49 000 ft) unless the equipment specified in OPS 1.680(a)(1) is serviceable, or the procedure prescribed in OPS 1.680(a)(2) is complied with.

2. the commander or the pilot to whom conduct of the flight has been delegated shall initiate a descent as soon as practicable when the limit values of cosmic radiation dose rate specified in the Operations Manual are exceeded.

***SUBPART K: INSTRUMENTS AND EQUIPMENT, OPS 1.680 Cosmic radiation detection equipment (L 254/139)***

(a) An operator shall not operate an aeroplane above 15 000 m (49 000 ft) unless:

1. it is equipped with an instrument to measure and indicate continuously the dose rate of total cosmic radiation being received (i.e. the total of ionising and neutron radiation of galactic and solar origin) and the cumulative dose on each flight, or

2. a system of on-board quarterly radiation sampling acceptable to the Authority is established.

***SUBPART P: MANUALS, LOGS AND RECORDS, Appendix 1 to OPS 1.1045, OPERATIONS MANUAL CONTENTS (L 254/213)***

An operator shall ensure the Operations Manual contains the following:

A. GENERAL/BASIC

8. OPERATING PROCEDURES

8.3.17. Procedures for aeroplanes operated whenever required cosmic or solar radiation detection equipment is carried. Procedures for the use of cosmic or solar radiation detection equipment and for recording its readings including actions to be taken in the event that limit values specified in the Operations Manual are exceeded. In addition, the procedures, including ATS procedures, to be followed in the event that a decision to descend or re-route is taken.

***SUBPART P: MANUALS, LOGS AND RECORDS, Appendix 1 to OPS 1.1045, OPERATIONS MANUAL CONTENTS (L 254/217)***

B. AEROPLANE OPERATING MATTERS – TYPE RELATED

Taking account of the differences between types, and variants of types, under the following headings:

3. ABNORMAL AND EMERGENCY PROCEDURES

3.1. The abnormal and emergency procedures and duties assigned to the crew, the appropriate check-lists, the system for use of the check-lists and a statement covering the necessary coordination procedures between flight and cabin crew. The following abnormal and emergency procedures and duties must be included:

(e) exceeding cosmic radiation limits;

***SUBPART P: MANUALS, LOGS AND RECORDS, OPS 1.1065 Document storage periods (L 254/206)***

An operator shall ensure that all records and all relevant operational and technical information for each individual flight, are stored for the periods prescribed in Appendix 1 to OPS 1.1065.

***Appendix 1 to 1.1065 Document storage periods, Table 6 Other records (L 254/222)***

An operator shall ensure that the following information/documentation is stored in an acceptable form, accessible to the Authority, for the periods shown in the Table below.

|  |  |
| --- | --- |
| Other records | |
| Records on cosmic and solar radiation dosage | Until 12 months after the crew member has left the employ of the operator |

## 11.1.3 UK CAP 393 Air Navigation: The Order and the Regulations

***SECTION 1, PART 6 FATIGUE OF CREW AND PROTECTION OF CREW FROM COSMIC RADIATION, Article 85 (Page 3)***

**Protection of crew from cosmic radiation**

**85** (1) A relevant undertaking shall take appropriate measures to:

(a) assess the exposure to cosmic radiation when in flight of those air crew who are liable to be subject to cosmic radiation in excess of 1 milliSievert per year;

(b) take into account the assessed exposure when organising work schedules with a view to reducing the doses of highly exposed air crew;

(c) inform the workers concerned of the health risks their work involves.

(2) A relevant undertaking shall ensure that in relation to a pregnant air crew member, the conditions of exposure to cosmic radiation when she is in flight are such that the equivalent dose to the foetus will be as low as reasonably achievable and is unlikely to exceed 1 milliSievert during the remainder of the pregnancy.

(3) Nothing in paragraph (2) shall require the undertaking concerned to take any action in relation to an air crew member until she has notified the undertaking in writing that she is pregnant.

(4) The definition in article 155 of “crew” shall not apply for the purposes of this article.

(5) In this article and in article 87:

(a) “air crew” has the same meaning as in article 42 of Council Directive 96/29/Euratom of 13th May 1996(a); and

(b) “undertaking” includes a natural or legal person and “relevant undertaking” means an undertaking established in the United Kingdom which operates aircraft.

(6) In this article:

(a) “highly exposed air crew” and “milliSievert” have the same respective meanings as in article 42 of Council Directive 96/29/Euratom of 13th May 1996; and

(b) “year” means any period of twelve months.

***SECTION 1, PART 7 DOCUMENTS AND RECORDS, Article 87 (Page 1)***

**Keeping and production of records of exposure to cosmic radiation**

**87** (1) A relevant undertaking shall keep a record for the period and in the manner prescribed of the exposure to cosmic radiation of air crew assessed under article 85 and the names of the air crew concerned.

(2) A relevant undertaking shall, within a reasonable period after being requested to do so by an authorised person, cause to be produced to that person the record required to be kept under paragraph (1).

(3) A relevant undertaking shall, within a reasonable period after being requested to do so by a person in respect of whom a record is required to be kept under paragraph (1), supply a copy of that record to that person.

***SECTION 1, SCHEDULE 4, Aircraft Equipment, Scale W (Page 4 & 35)***

Every aircraft of a description specified in the first column of the Table in paragraph 5 of this Schedule and which is registered in the United Kingdom shall be provided, when flying in the circumstances specified in the second column of the said Table, with adequate equipment, and for the purpose of this paragraph the expression “adequate equipment” shall mean, subject to paragraph 2, the scales of equipment respectively indicated in the third column of that Table.

**5 Table**

|  |  |  |
| --- | --- | --- |
| Description of Aircraft | Circumstances of Flight | Scale of Equipment Required |
| (2) Aeroplanes | (b) flying for the purpose of public transport; and  (xvii) when flying at an altitude of more than 49,000 ft | W |

**Scale W**

(1) Subject to paragraph (2), cosmic radiation detection equipment calibrated in millirems per hour and capable of indicating the action and alert levels of radiation dose rate.

(2) An aircraft shall not be required to carry the said equipment if before take-off the

equipment is found to be unserviceable and it is not reasonably practicable to repair or replace it at the aerodrome of departure and the radiation forecast available to the commander of the aircraft indicates that hazardous radiation conditions are unlikely to be encountered by the aircraft on its intended route or any planned diversion therefrom.

***SECTION 1, SCHEDULE 9, Public transport – operational requirements, PART A OPERATIONS MANUAL (Page 2)***

**1** Information and instructions relating to the following matters shall be included in the operations manual referred to in article 38(2):

(o) in the case of aircraft intended to fly at an altitude of more than 49 000 ft the procedures for the use of cosmic radiation detection equipment;

***SECTION 4 THE AIR NAVIGATION (COSMIC RADIATION)(KEEPING OF RECORDS) REGULATIONS 2000 (Page 1 & 2)***

The Secretary of State for the Environment, Transport and the Regions in exercise of the powers conferred by article 67 of the Air Navigation (No. 2) Order 1995(a) and all other powers enabling him in that behalf, hereby makes the following Regulations:

**Commencement and citation**

**1** (1) These Regulations may be cited as the Air Navigation (Cosmic Radiation) (Keeping of Records) Regulations 2000 and shall come into force on 15th June 2000.

(2) In these Regulations ‘the 1995 Order’ means the Air Navigation (No. 2) Order 1995.

**Period and requirements of the record of assessment**

**2** (1) The record of the exposure to cosmic radiation of air crew assessed under article 65A of the 1995 Order and required to be kept under article 67(1) of that Order shall meet the requirements of this regulation and in addition, as the case may be, the requirements of either paragraph (1) or paragraph (2) of regulation 3.

(2) A record kept under article 67(1) of the 1995 Order shall contain details of the assessment of the exposure to cosmic radiation for a period of at least twelve months, but not details of exposure before the coming into force of these Regulations.

(3) A record kept under article 67(1) of the 1995 Order shall be available for production as a paper record for a period of two years from the date each assessment was made, except that where the assessment shows that an individual is liable to cosmic radiation exposure in excess of 6 milliSieverts per year the record shall be available as a paper record until whichever is the later of either -

(a) the 75th anniversary of his birth, whether or not he has survived to that date, or

(b) the 30th anniversary of the termination of his work which involved exposure to cosmic radiation.

**3** (1) When an undertaking separately assesses the exposure to cosmic radiation of the individual members of the air crew, the undertaking shall keep a record of the exposure to cosmic radiation for each member of air crew assessed under article 65A of the 1995 Order, which record shall include –

(a) the name and national insurance number of the member of the air crew;

(b) the detail of each assessment of exposure expressed in milliSieverts per year; and

(c) the date of the assessment.

(2) When an undertaking does not separately assess the exposure to cosmic radiation of the individual members of the air crew, but instead assesses the exposure to cosmic radiation of groups of air crew members the undertaking shall keep a single record for all the air crew assessed under article 65A of the 1995 Order, which record shall state –

(a) the names and national insurance numbers of all air crew covered by the assessment;

(b) the maximum dose of cosmic radiation expressed in milliSieverts per year to which those air crew are liable to be exposed;

(c) how the dose in paragraph (b) is calculated; and

(d) the period for which the assessment is valid.

## 11.1.4 Other International Legislation

Additional legislation material needs to be sourced from all the international carriers……….

## 11.2 Guidance Material

## 11.2.1 FAA Civil Aerospace Medical Institute, Advisory Circular AC 120-61A

Information provided by the FAA’s Civil Aerospace Medical Institute (CAMI) on cosmic radiation, including the CARI-6 computer program that calculates galactic cosmic radiation, can be found using the following links:

1. CAMI Radiobiology Research Team website <http://www.faa.gov/education_research/research/med_humanfacs/aeromedical/radiobiology/>

2. The latest FAA Advisory Circular

<http://rgl.faa.gov/REGULATORY_AND_GUIDANCE_LIBRARY/RGADVISORYCIRCULAR.NSF/0/0e9f4e29ad41d6ce862571a7005a8288/$FILE/AC%20120-61A.pdf>

## 11.2.2 UK Department for Transport Guidance Material

The UK Government’s Cosmic Radiation Advisory Group (UK CRAG) provides guidance material to all UK AOC registered airlines on “Protection of air crew from cosmic radiation”. The latest version can be downloaded from the DfT website using the following link:

<http://www.dft.gov.uk/pgr/aviation/hci/protectionofaircrewfromcosmi2961>

## 11.2.3 Other International Guidance

Additional guidance material needs to be sourced from all the international carriers and added here………

# 12 Appendix G: National Variations - OPSPEC

# 13 Appendix H: National Variations – Radiation

# 14 Appendix I: IEEE Standards for Avionics

# 15 Appendix J: International Space Environment Service

This Appendix provides some background information on the International Space Environment Service (ISES), the Regional Warning Centres (RWCs) that make up the ISES network, and other information on how space weather is currently dealt with around the globe.

ISES is a permanent service of the Federations of Astronomical and Geophysical Data Analysis Services (FAGS) under the support of the International Union of Radio Science (URSI) in association with the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG).  
  
ISES was called IUWDS (International URSIgram and World Days Service) until 1996. The IUWDS was formed in 1962 as a combination of the former International World Days Service, initiated in 1959 as part of the IGY, and the former URSI Central Committee of USRIgrams which initiated rapid international data interchange services in 1928.

The mission of **ISES** is to encourage and facilitate near-real-time international monitoring and prediction of the space environment, to assist users reduce the impact of space weather on activities of human interest.

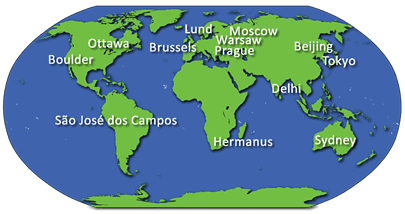


Figure. ISES Regional Warning Centres providing space weather services

At present, there are thirteen Regional Warning Centres around the world. These centres are located in [China (Beijing)](http://rwcc.bao.ac.cn/) , [USA (Boulder)](http://swpc.noaa.gov), [Russia (Moscow),](http://www.geospace.ru/) [India (New Delhi )](http://www.npl-cgc.ernet.in/atul/cgc/rwc/INTRUDUCTION4_BuIn.htm), [Canada (Ottawa)](http://www.spaceweather.gc.ca/), [Czech Republic (Prague)](http://rwcprague.ufa.cas.cz/), [Japan (Tokyo)](http://hirweb.nict.go.jp/index.html), [Australia (Sydney)](http://www.ips.gov.au/), [Sweden (Lund)](http://www.lund.irf.se/), [Belgium (Brussels)](http://sidc.oma.be), [Poland (Warsaw)](http://www.cbk.waw.pl/rwc/rwc.html), [South Africa (Hermanus)](http://spaceweather.hmo.ac.za) and [Brazil (São José dos Campos)](http://www.inpe.br/climaespacial/index.php). The [European Space Agency (Noordwijk)](http://www.estec.esa.nl/wmwww/wma/spweather/) is a collaborative expert centre providing a venue for data and product exchange for activities in Europe. In addition, the Associate Warning Centre in [France (Toulouse)](http://www.cls.fr/previsol/) provides specialized services to customers, and is affiliated through RWC Belgium. A data exchange schedule operates with each centre providing and relaying data to the other centres. The centre in Boulder plays a special role as "World Warning Agency", acting as a hub for data exchange and forecasts.

The data exchanged are highly varied in nature and in format, ranging from simple forecasts or coded information up to more complicated information such as images. An important strength of the data exchange system is that RWCs often have access to data from unique instrumentation available from the scientific community in its region. Exchange through ISES makes these data available to the wider international scientific and user community. The prime reason for the existence of the Regional Warning Centres is to provide services to the scientific and user communities within their own regions. These services usually consist of forecasts or warnings of disturbances to the solar terrestrial environment. The range of the locations of RWCs results in a very large diversity in the users of these forecasts. An important feature of the ISES system is that RWCs are able to construct and direct their services to the specific needs of their own customers.

Users of the services of RWCs include: high frequency (HF) radio communicators; mineral surveyors using geophysical techniques; power line and pipeline authorities; operators of satellites and a host of commercial and scientific users. The increasing sophistication and sensitivity of modern technology has resulted in a steadily expanding range of applications where a knowledge of the solar terrestrial environment is important.