International Civil Aviation Organization

THE SIXTH MEETING OF IONOSPHERIC STUDIES TASK FORCE (ISTF/6)

Bangkok, Thailand, 19 – 21 January 2016

Agenda Item 4f: Review of deliveries of Tasks and related Action Items

f) Task 6 - Space Weather

POTENTIAL OPERATIONAL IMPROVEMENTS THROUGH SPACE WEATHER SERVICES TO HELP MITIGATE THE EFFECTS OF SPACE WEATHER ON THE REGIONAL CNS SYSTEMS AND OPERATIONS

(Presented by Secretariat)

SUMMARY

This paper presents high level operational improvements that might be expected from delivery of Space Weather services to mitigate the effects of space weather on the regional CNS systems and operations.

1. INTRODUCTION

1.1 In response to the terms of reference of ISTF to "investigate the effects of space weather on CNS systems in the APAC Region", a document describing high level operational needs of Space Weather information to help mitigate the effects of space weather on the regional CNS systems and operations.

1.2 In its first version, it is a short document describing what space weather information is needed by CNS systems in APAC region. The information could be provided in the future by designated space weather service providers.

1.3 The development of provisions for information on space weather to international air navigation is being addressed by the METP. Regional planning and implementation of required space weather services will be supported by APANPIRG, specifically through the MET/SG, CNS/SG and ATM/SG.

2. DISCUSSION

Process to develop service-oriented requirements

2.1 After discussion during ISTF webconference #7 held on 24 September, 2015, it was agreed that a two-step approach should be taken:

- The first step is to identify operational needs irrespective of their feasibility, as this feasibility should be addressed through the work of the METP/WG-MISD.

- The second step is to examine their feasibility and whether the corresponding space weather solutions are global (and should be considered for inclusion at the global level accordingly) or regional only.

2.2 The document placed in **Appendix A** is the outcome of the first step. It includes 10 requirements in the areas of communications, navigation and surveillance.

2.3 Space weather information would not need to be presented to the ATC on a continuing basis. The principle followed is that concerned operators would be warned or alerted when the predicted impact is very likely to affect the services delivered by the operators themselves.

3. ACTION REQUIRED BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper;

b) discuss the requirements identified ; and

c) discuss the way forward and any relevant matters as appropriate.

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Operational needs of Space Weather services
for CNS systems
Version 3 – 13 Jan. 2016

1. Introduction

Space weather can be defined as the conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health of aviation flight crews and passengers [1]. This should be consistent with relevant discussion/outcomes on the definition for space weather from the METP/WG-MISD.

A Space Weather Concept of Operations [2] is being revised by the WG-MISD for endorsement by the METP.

In response to the **terms of reference of ISTF to "investigate the effects of space weather on CNS systems in the APAC Region",** this paper summarizes the operational requirements for space weather information in support of CNS systems as foreseen in the APAC region. They could constitute a good input to the discussions of the METP/WG-MISD.

This paper focuses on the operational benefits which could be reaped from space weather information services. Therefore, what is expected from space weather services may not be feasible at the current stage of space weather knowledge.

For those operational improvements whose benefit would be confirmed on a global scale, appropriate coordination with the METP will be undertaken for potential incorporation into the Concept of Operations for International Space Weather Information in Support of Aviation [2].

2. Operational improvements for space weather services

2.1 Communications

Space Weather phenomena can affect propagation of radio waves used for aeronautical communications. Following COM systems may be influenced:

[i] HF communications may be disturbed by solar X-ray flare. Increased solar X-ray enhances the ionospheric density in the D-region to absorb HF radio waves (Dellinger phenomenon), and long-distance HF communications may be disrupted.

<table>
<tr><td colspan="2">Operational improvement SW-COM-1:</td></tr>
<tr><td colspan="2">a) Monitor the predicted impact of HF propagation conditions on high frequency aeronautical mobile communications (controller / pilot) over the next 24 hours in volumes of airspace (ATS) and along trajectories of the subscribed users (ATS units and airspace users)
b) Warn concerned users when the predicted impact is very likely to affect the communications such that the Mean opinion score (MOS) equals 3 (fair quality) and publish the description of affected volume of airspace (ATS) and trajectories
c) Alert concerned users when the predicted impact is very likely to affect the communications such that the MOS equals 2 or less (poor or bad) and publish the description of affected volume of airspace (ATS) and trajectories</td></tr>
<tr><td>☒Global ☒APAC</td><td>☒ Safety ☐ Efficiency/Capacity ☐ Environment</td></tr>
</table>

Notes:

- *impact should be easily understandable by ATS/ATFM units and air operators and be characterized using the Mean opinion score (MOS) as per ITU-T recommendation P.800. MOS rates the quality of the voice signal in one of the following categories: excellent (5), good (4), fair*

(3), poor (2) and bad (1)

- *volume of airspace (ATS) and trajectory descriptions should use FIXM (see http://fixm.aero/)*
- *description and presentation of impacts should be based on AIXM/IWXXM*
- *the forecast window of 24 hours was taken considering a 6 to 12 hours before takeoff for appropriate preparation of flights and ATFM/ATS units, a cruise of 12 hours and an additional margin of 6 hours*

HF communications through the polar region may be disrupted by sudden enhancement of high-energy particle precipitations in the polar cap region to enhance HF radio absorption (polar cap absorption: PCA).

Operational improvement SW-COM-2:	
a) Monitor the predicted impact of high-energy particle precipitations in the polar cap region on high frequency aeronautical mobile communications (controller / pilot) through the polar region over the next 24 hours in volumes of airspace (ATS) and along trajectories of the subscribed users (ATS units and airspace users) b) Warn concerned users when the predicted impact is very likely to affect the communications such that the MOS equals 3 (fair quality) and publish the description of affected volume of airspace (ATS) and trajectories c) Alert concerned users when the predicted impact is very likely to affect the communications such that the MOS equals 2 or less (poor or bad) and publish the description of affected volume of airspace (ATS) and trajectories	
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Notes:

- *impact should be easily understandable by ATS/ATFM units and air operators and could be characterized using the Mean opinion score (MOS) as per ITU-T recommendation P.800*
- *volume of airspace (ATS) and trajectory descriptions should use FIXM (see http://fixm.aero/)*
- *description and presentation of impacts should be based on AIXM/IWXXM*

These are global phenomena.

[ii] VHF communications may suffer from interferences by anomalous radio propagation associated with the sporadic E layer. The sporadic E-layer reflects VHF radio waves to cause long-distance propagation to reach beyond the radio horizon.

Monitoring and predicting the Es layer conditions are desirable.

Operational improvement SW-COM-3:	
a) Monitor the predicted impact of interferences by anomalous radio propagation associated with the sporadic E layer on very high frequency aeronautical mobile communications (controller / pilot) over the next 24 hours in volumes of airspace (ATS) and along trajectories of the subscribed users (ATS units and airspace users). b) Warn concerned users when the predicted impact is very likely to affect the communications such that the MOS equals 3 (fair quality) and publish the description of affected volume of airspace (ATS) and trajectories c) Alert concerned users when the predicted impact is very likely to affect the communications such that the MOS equals 2 or less (poor or bad) and publish the description of affected volume of airspace (ATS) and trajectories	
☒Global ☒APAC	☒ Safety ☐ Efficiency/Capacity ☐ Environment

Notes:

- *impact should be easily understandable by ATS/ATFM units and air operators and characterized using the Mean opinion score (MOS) as per ITU-T recommendation P.800*
- *volume of airspace (ATS) and trajectory descriptions should use FIXM (see http://fixm.aero/)*

- *description and presentation of impacts should be based on AIXM/IWXXM*

Sporadic E layer is a localized phenomenon.

[iii] L-band satellite communications may be disturbed by scintillations by irregularities in the ionosphere. In the low latitude region, small-scale irregularities in the ionosphere associated with plasma bubbles may cause scintillations in L-band satellite communication radio waves to cause degrading communications or lock-off of satellite signals.

As per [4] aviation users of the satellite segment in L-Band are Inmarsat, MTSAT and Iridium systems.

For Inmarsat and Iridium the potential impact regards ACARS, FANS and ATN communications, Electronic Flight Bag (EFB) data streaming and in the future the flight tracking systems.

<table>
<tr><td colspan="2">Operational improvement SW-COM-4:</td></tr>
<tr><td colspan="2">a) Monitor the impact of scintillations (plasma bubbles) in L-band satellite communication radio waves on data communication performance for:
a. ACARS, FANS and ATN communications;
b. Electronic Flight Bag (EFB) data streaming and;
c. Flight tracking systems.
b) Warn concerned users, including communication service providers, when the predicted impact will very likely degrade the performance of CPDLC, ADS-C, EFB or Flight tracking service and publish the description of affected volume of airspace (ATS) and trajectories.
c) Alert concerned users when the predicted impact is very likely to cause the loss of CPDLC, ADS-C, EFB or Flight tracking service and publish the description of affected volume of airspace (ATS) and trajectories</td></tr>
<tr><td>☒Global ☒APAC</td><td>☒ Safety ☒ Efficiency/Capacity ☐ Environment</td></tr>
</table>

Plasma bubble is a localized phenomenon.

2.2 Navigation

Space Weather phenomena can affect propagation of radio waves used for aeronautical navigations. Following systems may be influenced:

[i] Effects of space weather phenomena are summarized in [3] as parts of GBSS vulnerability. Followings are among them

(a) Ionospheric propagation delay in GNSS signals is proportional to the ionospheric total electron contents (TECs). Different classes of ionospheric TEC disturbances can be error sources in GNSS. Phenomena that accompany TEC disturbances include the day-to-day variation of equatorial ionization anomaly, positive ionospheric storms associated with magnetic storms, and plasma bubbles.

(b) Ionospheric scintillation is caused by small-scale irregularities in the ionosphere. The effects are similar to those on the L-band satellite communications. In the low latitude region, it is associated with plasma bubbles.

(c) Solar radio burst is a sudden enhancement in the radio flux radiated by the sun. Enhancement in the solar radio flux in the GNSS signal bands degrades signal-tonoise ratio of GNSS signals to degrade the accuracy, and in the worst case cause lock-off of signals.

Monitoring and Predicting plasma bubbles are desirable for (a) and (b). Monitoring and predicting magnetic storms and resulted TEC variations are desirable for (a). Monitoring and predicting solar radio burst are desirable for (c).

Operational improvement SW-NAV-1:	
a) Monitor and predict the variation of TECs (ionospheric delays) and their disturbances over the next 24 hours in volumes of airspace (ATS), aerodromes and along trajectories of the subscribed users (ATS units, airport operators and airspace users). b) Warn concerned users, including RAIM prediction service suppliers, when the predicted impact will increase the a priori probability of ionospheric disturbances and publish the description of affected volume of airspace (ATS), aerodromes and trajectories.	
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Note: Current augmentation systems (SBAS, GBAS) assume a priori probability of ionospheric disturbances as 1 (always there), which is very conservative. Such prediction would reasonably decrease the a priori probability and result in enhancing availability of GNSS -based systems.

Operational improvement SW-NAV-2:	
a) Monitor and predict the impact of scintillations by plasma bubbles on GNSS signals over the next 24 hours in volumes of airspace (ATS), aerodromes and along trajectories of the subscribed users (ATS units, airport operators and airspace users). b) Warn concerned users, including RAIM prediction service suppliers, when the predicted impact will increase the a priori probability of ionospheric disturbances and publish the description of affected volume of airspace (ATS), aerodromes and trajectories.	
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Note: Since scintillations have direct impact on available satellites, this improvement could be a part of RAIM prediction.

Operational improvement SW-NAV-3:	
a) Monitor and predict the impact of solar radio bursts on GNSS signals over the next 24 hours in volumes of airspace (ATS), aerodromes and along trajectories of the subscribed users (ATS units, airport operators and airspace users). b) Warn concerned users, including RAIM prediction service suppliers, when the predicted impact will increase the a priori probability of ionospheric disturbances and publish the description of affected volume of airspace (ATS), aerodromes and trajectories.	
☒Global ☐APAC	☒ Safety ☐ Efficiency/Capacity ☐ Environment

[ii] VHF ground radio navigation aids may suffer from interferences by anomalous radio propagation associated with the sporadic E layer. The sporadic E-layer reflects VHF radio waves to cause long-distance propagation to reach beyond the radio horizon. Monitoring and predicting the Es layer conditions are desirable.
Sporadic E layer is a localized phenomenon.

Operational improvement SW-NAV-4:	
a) Monitor and predict the impact of sporadic Es layer conditions on actual navigation performance in volumes of airspace (ATS), aerodromes and along trajectories of the subscribed users (ATS units, airport operators and airspace users). b) Warn concerned users, including RAIM prediction service suppliers, when the predicted impact will increase the a priori probability of ionospheric disturbances and publish the description of affected volume of airspace (ATS), aerodromes and trajectories.	
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Note: Solar radio bursts are global phenomena, though it is strongest at sub-solar points on the Earth.

2.3 Surveillance

Surveillance systems which utilize GNSS such as ADS-B and ADS-C may be impacted by space weather phenomena as a consequence of space weather impact on GNSS.

Operational improvement SW-SUR-1:	
a) Monitor and predict the effects on ADS-B of space weather impact on GNSS in volumes of airspace (ATS) and along trajectories of the subscribed users (ATS units and airspace users). b) Warn concerned users when the positions reported will not meet the performance criteria and publish the description of affected volume of airspace (ATS) and trajectories. c) Alert concerned users when the predicted impact is very likely to cause the loss of ADS-B service and publish the description of affected volume of airspace (ATS) and trajectories.	
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Notes:

- *Ionospheric TEC variations and scintillations may degrade the position accuracy of GNSS-based position solutions which are piped to ADS-B outputs. Whether such impacts really exist has to be confirmed.*
- *As a first approach there would be no need for the ATS units/ATM systems to discriminate ionospheric effects from other effects affecting NUC or NIC,NAC,SIL. What is of interest is whether the positions reported do meet or not the performance criteria.*

Operational improvement SW-SUR-2:	
a) Monitor and predict the effects on ADS-C of space weather impact on GNSS in volumes of airspace (ATS) and along trajectories of the subscribed users (ATS units and airspace users). b) Warn concerned users, including communication service providers, when the predicted impact will very likely degrade the performance of ADS-C and publish the description of affected volume of airspace (ATS) and trajectories. c) Alert concerned users when the predicted impact is very likely to cause the loss of ADS-C service and publish the description of affected volume of airspace (ATS) and trajectories.	
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Notes:

- *Ionospheric TEC variations and scintillations may degrade the position accuracy of GNSS-based position solutions which are piped to ADS-C outputs. Whether such impacts really exist has to be confirmed.*
- *As a first approach there would be no need for the ATS units/ATM systems to discriminate ionospheric effects from other effects affecting FOM. What is of interest is whether the positions reported do meet or not the performance criteria.*

3. References

[1] WMO Space Programme SP-5, The Potential Role of WMO in Space Weather, April 2008.

[2] Concept of Operations for International Space Weather Information in Support of Aviation, Draft version 3.0, 6 December 2013.

[3] WP/21, Global navigation satellite system (GNSS) implementation issues, AN-Conf/12, November 2012.

[4] ICAO Doc 9718 AN/957 Handbook on Radio Frequency Spectrum Requirements for Civil Aviation Volume I