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Sino-Russian Space Weather Effort for Global Air Navigation Safety

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This paper covers the role of the China-Russia Consortium in Global Air Navigation Safety, how space weather centers for aviation were established and how are they regulated. We briefly introduce the effects of space weather on aviation in general. A short description of the ICAO-designated space weather service fol-lows. The China-Russia Consortium history, members and the way it integrates into the global service are described afterwards.

Keywords: space weather, air navigation, civil aviation, ionizing radiation, GNSS, X-ray bursts, solar flares, HF communications, radiation dosimetry

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1 Introduction

Space weather events such as X-ray flares, X-ray bursts and CMEs are potentially hazardous for air navigation safety. The major risks come from ionizing radiation hazard for the crew, passengers and avionics, satellite navigation capability degradation and voice communication deterioration. The ionizing radiation that comes from solar events directly or through the cascade of solar energetic particles collisions in the upper atmosphere poses a substantial risk to crew and passengers aboard the aircraft at cruising altitudes. During greater solar events the effective dose at these altitudes may rise first tens of mSv [*Aleshin et al.*, 2021; *Cannon et al.*, 2013], that is greatly in excess of the annual dose rate for the general public. For example, during calm space weather, long-haul flights crew typically accumulate 1 to 6 mSv [*EURADOS*, 2004] per year. The same risk affects the onboard avionics causing "single event effects". These effects cause integrated circuits to fail because of a sudden change of logic state inflicted by energetic particles. In recent years avionics systems became more redundant and specifically designed to be resistant to these effects, however, there is a know case of failure of this type to cause incident [*ATSB*, 2011]. Solar events also energize the ionosphere, this may degrade the accuracy of both onboard GNSS receivers and ground augmentation stations. Accuracy degradation is not the only problem caused by space weather. Solar radio bursts, phase and amplitude scintillations also cause GNSS navigation to lose accuracy or to fail. High-frequency communication uses a band of 3–30MHz. This type of communication is generally used as an over-horizon method of communication. This is possible because of the physical properties of the ionosphere which reflects the radio waves in this frequency band. However, when the ionosphere is being energized by the energetic particles the available radio band shrinks down to total HF radio blackout. When this happens the aircraft can no longer communicate with the over-the-horizon party because the ionosphere absorbs rather than reflects the radio waves.

2 Duty of Space Weather Centres for Aviation

The International Civil Aviation Organization issues standards and practices for global civil aviation. Among those is "Annex 3 to Convention on International Civil Aviation: Meteorological Service for International Air Navigation". In its 77th amendment, the document defined the space

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Table 1 – Advisories, effects and thresholds mandated for issuance.

Effect Category	Anomaly / Observation	Moderate threshold	Severe threshold
GNSS	Vertical Total Electron Content	125 TECU	175 TECU
GNSS	Amplitude Scintillation/S4	0.5	0.8
GNSS	Phase Scintillation/$\sigma\phi$	0.4 rad	0.7 rad
Radiation	Effective dose rate	30 μSv/hour	80 μSv/hour
HF COM	Auroral Absorption / Planetary Geomagnetic Index	8	9
HF COM	Polar Cap Absorption/Attenuation	2 dB	5 dB
HF COM	Shortwave Fadeout / X-ray flux	10^{-4} W/m^2	10^{-3} W/m^2
HF COM	Post-storm Ionospheric Depression / Proportion of Maximum Usable Frequency Decrease	0.3	0.5

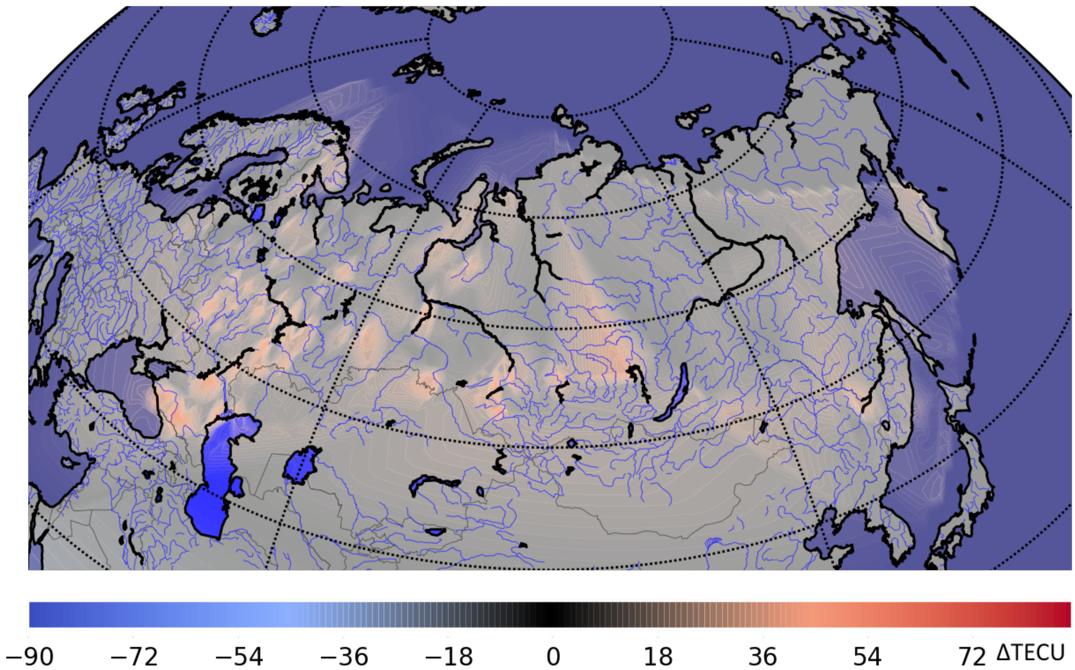

Figure 1 – TEC anomaly map over the territory of the Russian Federation. Calm space weather. The anomaly is calculated against SIMP2 model.

weather service and obligations of space weather centres. Throughout the evolution of the Convention and work several international workgroups of both technical and scientific experts and industry and state representatives the whole concept of service developed into a well-defined set of rules and recommendations. Today the space weather service for aviation issues four types of warnings, the advisories, on space weather effects and corresponding fore-casts.

Each centre monitors the space weather and provides advisories to the industry. These advisories fall into four groups: radiation, GNSS, high-frequency communication and two-way satellite communication. The radiation advisory tells about the expected growth of radiation dose rate on certain flight levels in high latitudes. The exact values for moderate and severe effects in uSv/h are mandated in the Convention, see summary in Table 1. GNSS advisories are issued when specific values of total electron content, amplitude and phase scintillations exceed the mandated moderate or severe values. In this case, the advisory is supplemented by more detailed effect location informa-

Figure 2 – Map of countries involved in ICAO space weather service.

tion. See Figure 1 for calm weather anomaly distribution. High-frequency communication degradation advisories are issued when specific X-ray flux, planetary geomagnetic index, auroral cap absorption exceeds the defined values. Additionally, the maximum usable frequency dynamics during the post-storm depression of the ionosphere also triggers this advisory. Two-way satellite communication is currently not monitored and is not provided advisories on. This is because both the observation and thresholds are not yet set with regulating documents. There is an ongoing discussion on this topic within the workgroups of ICAO, industry and scientific community. The space weather centre updates the advisories as the situation develops or subsides.

The advisories come in two formats - traditional alphanumeric format(TAC) and XML-based format called IWXXM [*ICAO*, 2014]. TAC advisories are transferred via Aeronautical Fixed Telecommunication Network via national and regional hubs around the world and IWXXM uses another system called Aviation Message Handling System.

3 Global Centers and CRC

Initially, several countries expressed a will to enter space weather service and under-went audit on institutional, operational, technical and communication aspects. Both the Russian Federation and the People's Republic of China, along with other countries and consortia, were declared compliant. However, only three global space weather centres started duty service on the 7th of November 2021 [*ICAO*, 2019a]. These centres are:

- ACFJ consortium (comprising Australia, Canada, France and Japan)
- PECASUS consortium (comprising Austria, Belgium, Cyprus, Finland, Germany, Italy, Netherlands, Poland, the United Kingdom, and South Africa)
- Space Weather Prediction Center (USA)

The coordination of these centers is accomplished by Space Weather Centers Coordination Group (SWxCCG) of Meteorology Panel of the Air Navigation Commission of ICAO. The routine duty includes operation on two-week rotational basis. Within the coordination group centers have developed procedures for handover and failover in emergency situations. The coordination group also works on consistency, communication, and development of the space weather service. The ICAO also published manuals for end users: [*ICAO*, 2019b, 2021]. In spring 2020 the ICAO Council agreed that Russia and China would form a consortium and enter service in fall 2021 without any additional audit [*ICAO Assembly*, 2019]. The newly formed China-Russia Consortium (CRC) started internal integration processes. The SWxCCG also established a workgroup for CRC to smoothly enter the service. In general, the integration process involves consistency compliance, setting up advisory dissemination and testing, testing internal and handover procedures. Map of involved countries is shown on Figure 2. The CRC currently comprises three organizations: the Aviation Meteorological Centre (AMC) of the Civil Aviation Administration of China (CAAC), National Center for Space Weather (NCSW) of China Meteorological Administration (CMA) and Fedorov Institute of Applied Geophysics (IAG) of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). The joint capabilities include several space vehicles (Elektro-L and Fengyun series), riometer and GNSS ground station networks, ionospheric sounders. Space weather centers of NCSW and IAG show high level of automation and redundancy.

4 Conclusion

The joint Sino-Russian effort for mitigation of the newly recognized threat of solar events would augment global space weather service for air navigation safety. The quality of effect detection and accuracy of forecasts would improve over time as new observatories established and new methods implemented. However, there still much effort has to be put into data sharing. Because GNSS ground station data, as well as magnetometric data, is often considered sensitive and is prohibited for export [*Kahveci*, 2017] (or otherwise cannot be easily shared). Centres work with government and data network officials to improve the situation.

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