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Bangkok, Thailand, 18 - 22 August 2025

Agenda Item 5: Planning and monitoring

CONSOLIDATED SPACE WEATHER INFORMATION SERVICE MANAGEMENT REPORT FOR 2024

(Presented by Australia)

SUMMARY

This information paper presents the first consolidated management report for the Space Weather Information Service which was approved by the Meteorology Panel (METP) Working Group on Meteorological Operations Groups (WG-MOG) for Space Weather (SWX) Work Stream. The reporting period is from 1 January to 31 December 2024.

1. INTRODUCTION

1.1 The ICAO SWX Information Service (SWIS) became operational on 7 November 2019. The operation of SWIS is overseen by the METP WG-MOG SWX Work Stream and managed by the Space Weather Centre Coordination Group (SWXC CG), which is comprised of four global and one regional SWXC designated by ICAO.

1.2 After nearly 4 years of operational experience with SWIS, the WG-MOG SWX Work Stream formally requested that the SWXC CG develop an annual management report for SWIS to support the oversight responsibilities of the METP. Thus, at the 24th meeting of the WG-MOG (28 November – 1 December 2023, Brussels) the group agreed to take an action to produce a consolidated management report from 1 January to 31 December 2024.

2. DISCUSSION

2.1 The content of the SWIS consolidated management report closely resembles that of the consolidated management report for the International Airways Volcano Watch (IAVW). The outline of the SWIS consolidated management report is presented in the table below. The full report can be found in Appendix A.

Content of Consolidated Management Report for the Space Weather Information Service	
Executive summary	2.5 Operational continuity of service
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1.0 Introduction	ACFJ report
2.0 Discussion on operations	CRC report
2.1 Space weather conditions in 2024	PECASUS report
2.2 Overview of advisories issued per centre	SWPC report
2.3 Finding on the useability of advisories	SANSA report
2.4 Results of key performance indicators	Appendix A: Requirements for space weather centres

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper.

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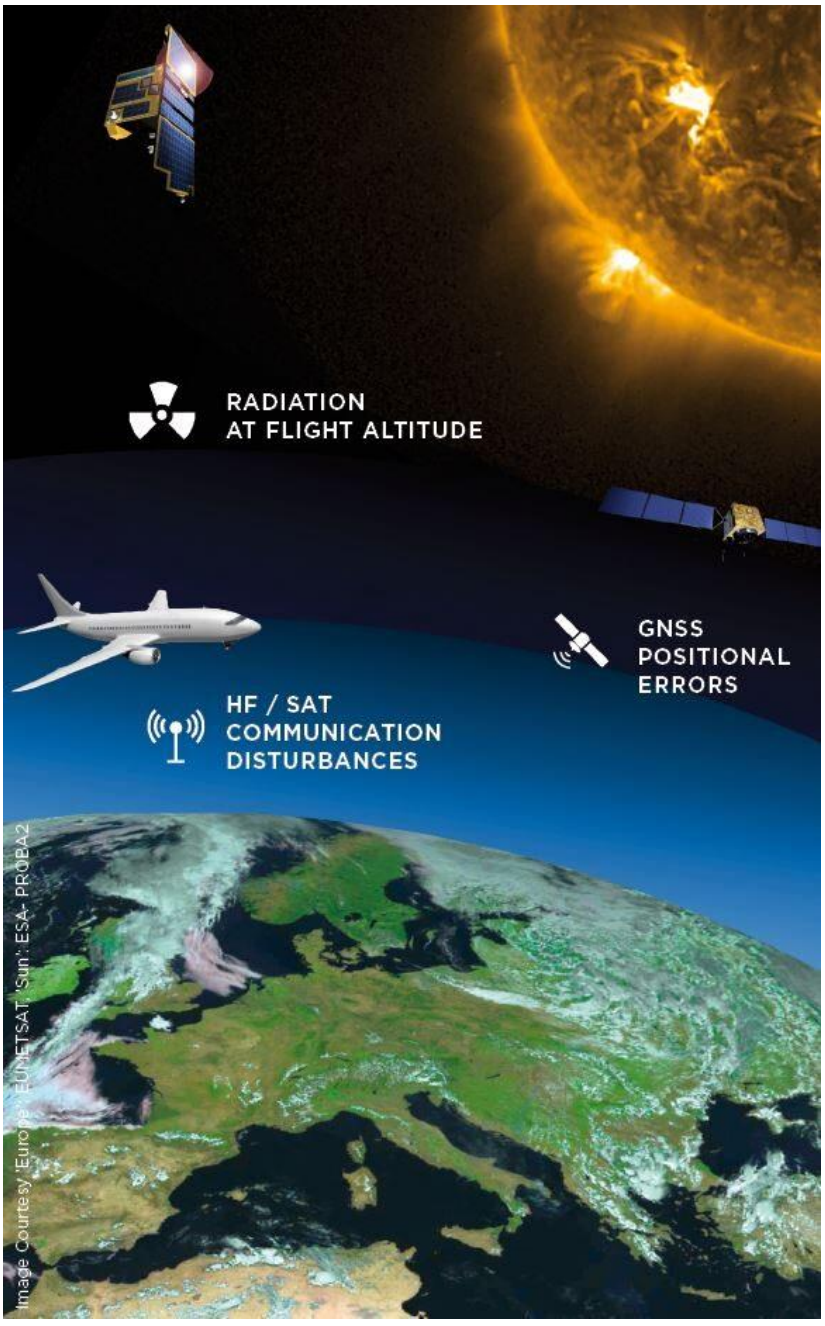
APPENDIX A

Consolidated Space Weather Information Service Management Report for 2024



Version	Date	Change record	Approved
1.0	18 June 2025	Final	MOG-SWX work Stream

EXECUTIVE SUMMARY

The International Civil Aviation Organization (ICAO) Space Weather (SWX) Information Service (SWIS) became operational on 7 November 2019. The operation of the SWIS is managed by the SWX Centre (SWXC) Coordination Group (SWXCCG) which is comprised of the four global SWXCs and one regional SWXC designated by ICAO to provide the service. The ICAO Meteorology (MET) Panel (METP) is responsible for overseeing the operation of the SWIS. This responsibility is delegated to the SWX Work Stream under the METP Working Group on MET Operations Groups (WG-MOG).

To facilitate the execution of its oversight responsibilities, the WG-MOG SWX Work Stream requested that the SWXCCG produce an annual report on the operation of the SWIS beginning with calendar year 2024 (1 January to 31 January). The annual report on the operation of the SWIS is based on the consolidated management reports produced by the ICAO-designated providers of the International Airways Volcano Watch (IAVW) and the World Area Forecast System (WAFS).

The consolidate SWIS management report includes input from the four global SWXCs and the one regional SWXC about the operation of the SWIS, further development and improvements of the SWIS, and select activities of each SWXC relevant to the SWIS. The content of the report is intended to assist the SWXCs in identifying and mitigating any issues with the provision of the SWIS, as well as communicating the performance of the SWIS to the various user communities and stakeholders that utilize space weather information for international civil air navigation.

This first consolidated SWIS management report marks a milestone in the ongoing development and improvement of the SWIS with the completion of 5 years of operational service in November 2024. However, the consolidated SWIS management report is expected to change over time as the service changes in response to the needs and requirements of aviation decision-makers, as well as technological and operational improvements implemented by the designated SWXCs. Thus, the content and format of the consolidated SWIS management report for future years may differ significantly from this first report for 2024.

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ACRONYM LIST

ACFJ	Consortium comprised of Australia, Canada, France and Japan
AMD	Amendment (to ICAO Annex 3 and PANS-MET)
CMA	China Meteorological Administration
CLS	Collecte Localisation Satellite
CRC	Consortium comprised of People's Republic of China and Russian Federation
EACCC	European Aviation Crisis Coordination Cell
ESSP	European Satellite Service Provider
ET-SWx	Expert Team on Space Weather
EUROCONTROL	European Organisation for the Safety of Air Navigation. A Pan-European, civil-military organization dedicated to supporting European aviation
EUV	Extreme Ultraviolet
FY	FengYun satellite series
FMI	Finnish Meteorological Institute
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite (USA)
GOMS	Geostationary Operational Meteorological Satellite (Russia)
HF COM	High Frequency Communications
IAG	International Association of Geodesy
ICAO	International Civil Aviation Organization
INFCOM	Commission for Observation, Infrastructure and Information Systems of the World Meteorological Organization
ISO	International Organization for Standardization
KNMI	Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut)
KPI	Key Performance Indicator
MOC	Maintenance and Observation Centre
NOAA	National Oceanic and Atmospheric Administration
NR RPLC	No Replacement Number
ODC	On Duty Centre
PANS-MET	Procedures for Air Navigation Services – Meteorology
PBC	Primary Backup Centre
PECASUS	Pan-European Consortium for Aviation Space Weather User Services (Consortium comprised of Finland, United Kingdom, Belgium, Austria, Cyprus, Germany, Italy, Netherlands and Poland)
QMS	Quality Management System
RAD	Radiation
RD	Reference Document
RMK	Remarks
SANSA	South-African National Space Agency
SARPs	Standards and Recommended Practices
SBC	Secondary Backup Centre
STCE	Solar-Terrestrial Centre of Excellence
SWIS	Space Weather Information Service

SWPC	Space Weather Prediction Centre
SWX	Space Weather
SWXC	Space Weather Centre
SWXCCG	Space Weather Centre Coordination Group
TEC	Total Electron Content
UTC	Coordinated Universal Time
UV	Ultraviolet
WG-MOG	Working Group on Meteorological Operations Groups
WIS	WMO Information System
WMO	World Meteorological Organization
WS	Work Stream

REFERENCE DOCUMENT LIST

RD-1 ICAO Annex 3 20th Edition July 2018, https://store.icao.int/en/annex-3-meteorological-service-for-international-air-navigation

RD-2 Doc 10100 Manual on Space Weather Information in Support of International Air Navigation First Edition 2019, https://store.icao.int/en/manual-on-space-weather-information-in-support-of-international-air-navigation-doc-10100

RD-3 Report of the 5th meeting of the WMO ET-SWx, https://community.wmo.int/en/meetings/5th-meeting-expert-team-space-weather-30-october-1-november-2024

RD-4 Space Weather Information Service Demonstration Process. Audit procedures and reporting templates, 19 January 2018, WMO Secretariat.

1. INTRODUCTION

Space weather (SWX) constitutes a potential risk to aviation. To mitigate these risks, it was recognized that a SWX Information Service (SWIS) would be beneficial to the aviation sector. SWX has been included in the International Civil Aviation Organization (ICAO) Annex 3 since the Twentieth Edition, July 2018. Resulting from ICAO State Letter AN 10/1-IND/17/11 (dated June 9, 2017) with the *Request for interest in providing a space weather information service*, a number of countries and consortiums comprised of several partnered countries, were audited against the ICAO requirements to provide SWX services. These requirements are listed in Appendix A. Based on the successful audits of these SWX Centres (SWXCs) and two ICAO Council decisions, four global SWXCs and one regional SWXC were eventually designated by ICAO. Operations started on 7 November 2019. The integration process of one regional SWXC is ongoing and is expected to be completed by July 2025.

Four global SWXCs were designated by the ICAO Council at the seventh meeting of its 215th Session on 13 November 2018 (Council decision C-DEC 215/7). These SWXCs are:

- The ACFJ consortium formed by Australia, Canada, France and Japan (http://www.bom.gov.au/aviation/space-weather-advisories/).
- The CRC consortium formed by the People's Republic of China and the Russian Federation joined the operations starting in December 2020. (https://www.spaceweather-service.com).
- The Pan-European Consortium for Aviation Space weather User Services (PECASUS) formed by Finland (lead), Belgium, United Kingdom, Poland, Germany, Netherlands, Italy, Austria, and Cyprus (https://pecasus.eu/).
- The Space Weather Prediction Centre (SWPC) of the National Oceanic and Atmospheric Administration (NOAA) in the United States of America (https://www.swpc.noaa.gov/).

The only regional SWXC that will be shortly integrated into the global SWIS service is operated by the South-African National Space Agency (SANSA) (https://spaceweather.sansa.org.za/).
The four global SWXCs perform SWX monitoring and forecasting in two week shifts with one of the SWXCs serving as the On Duty Centre (ODC) and the others serving as Primary Backup Centre (PBC), Secondary Backup Centre (SBC) and Maintenance and Observation Centre (MOC). This scheme was chosen to optimize the availability of the combined SWXCs.

A SWX Centre Coordination Group (SWXCCG) is responsible for (off-line) coordinating operational activities and service improvements. Further service improvements are also discussed by the ICAO Meteorology Panel's (METP) Working Group on Meteorological Operations Groups (WG-MOG) SWX Work Stream (WS) and its ad hoc groups. The METP WG-MOG SWX WS is also responsible for the preparation of proposals for Amendments (AMDs) to Annex 3 and the *Procedures for Air Navigation Services — Meteorology* (PANS-MET). Improvements in standards and practices for SWX in general are discussed by the Expert Team on Space Weather (ET-SWx) of the Commission for Observation, Infrastructure and Information Systems (INFCOM) of the World Meteorological Organization (WMO).

This report constitutes the first SWIS Management Report for the combined SWXCs over the period 1 January – 31 December 2024[1]. Because the SWIS is still a relatively new system, it is foreseen that

[1] This report is comprised of elements taken from the Consolidated Volcanic Ash Advisory Centre Management Report and the World Area Forecast System Management Report.

the content of this Management Report and the Key Performance Indicators (KPIs) will evolve over the coming years, thereby moving from performance-based toward more quality-based KPIs.

The outline of this report is as follows. In Section 2, the SWX conditions in 2024 are discussed together with various statistics about the advisories that have been issued by each global SWXC. Additionally, minor errors in the advisories are also discussed and the KPIs are introduced. Special attention is paid to the continuity of the SWIS in regard to the ICAO requirements. In Section 3, future developments and service improvements are discussed. A description of selected activities by each SWXC is included in Section 4.

2. DISCUSSION OF OPERATIONS

2.1 Space Weather Conditions in 2024

This section presents the SWX conditions in 2024. The year 2024 coincided with the maximum of the solar cycle. Figure 1 shows the solar activity cycles since 1985 (top) and the activity in 2024 (bottom). Operations by the four global SWXCs started during solar minimum in 2019 and covered the ascending phase of the solar cycle.

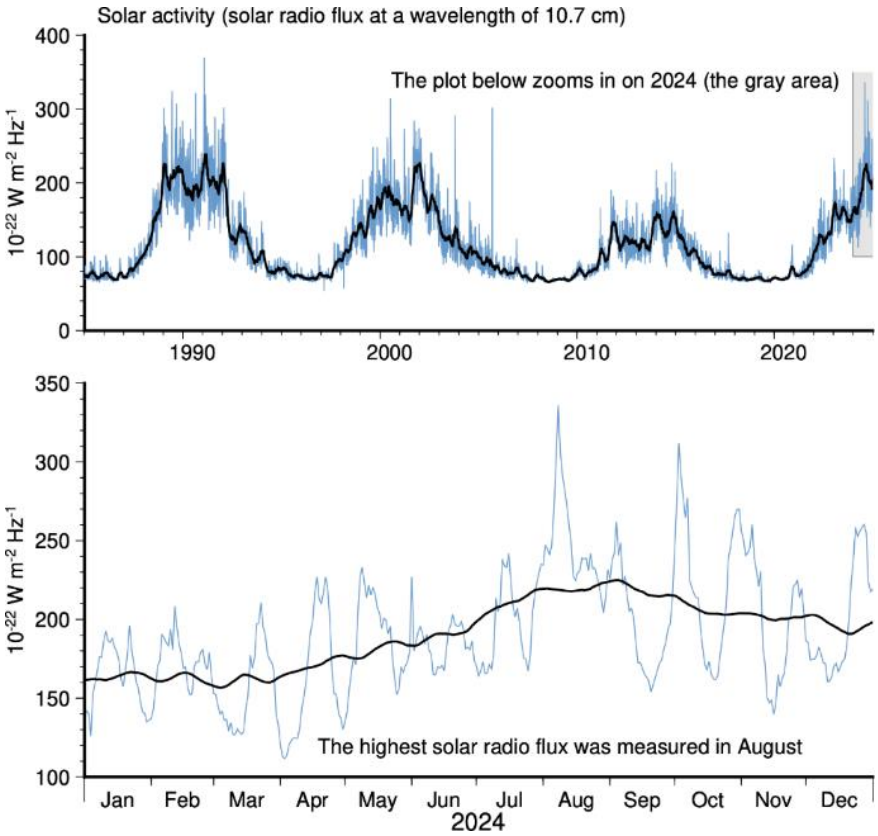

Figure 1. Solar activity over the period 1985-2025 (top panel) and during 2024 (bottom panel) as measured with the F10.7 cm radio flux, a commonly used activity indicator.

Figure 2 provides a detailed overview of solar activity in 2024 including X-ray flares, high-energy particle events, the interplanetary magnetic field and solar wind, and the magnetic Kp index.
All these parameters are measured near the Earth by the Geostationary Operational Environmental Satellites (GOES) apart from the magnetic Kp index that is proved by GFZ Potsdam.

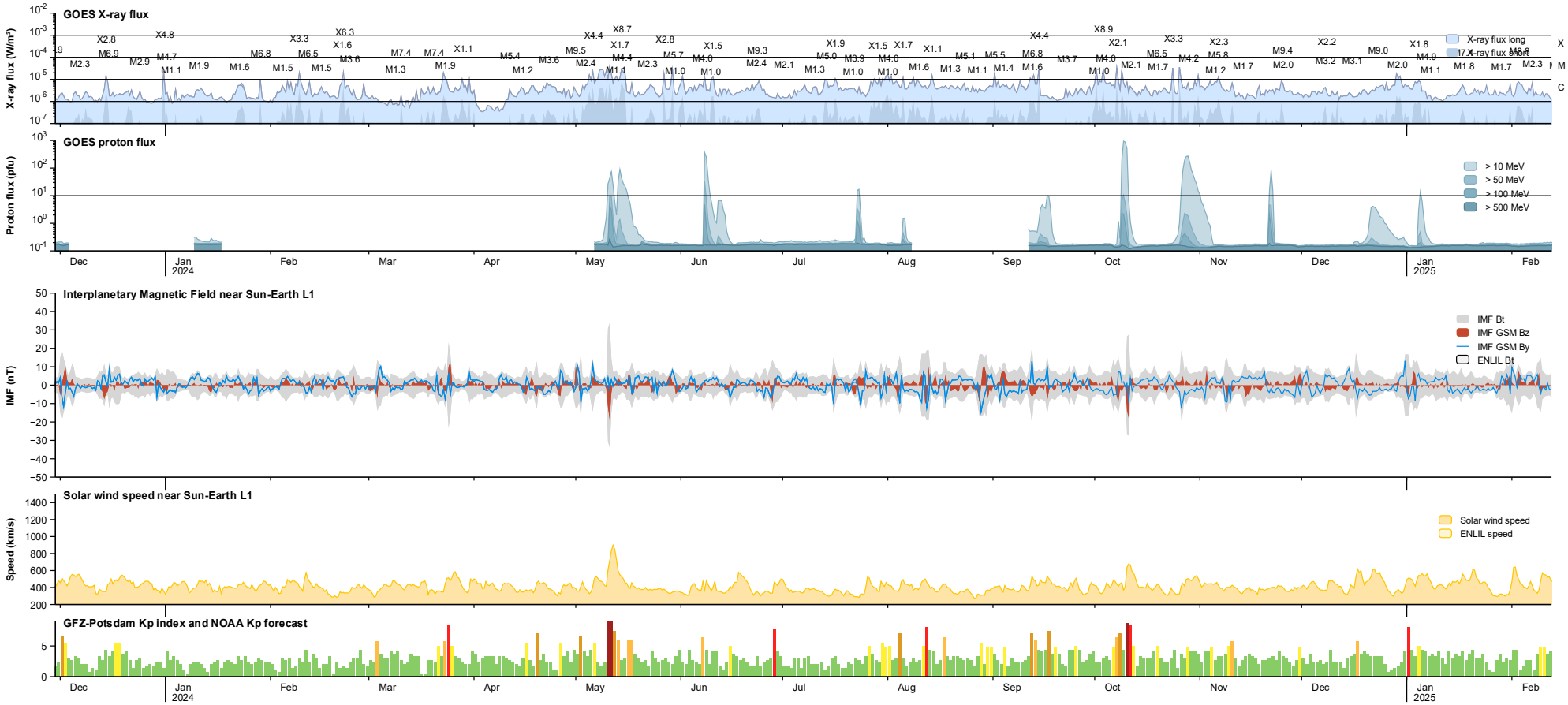

Figure 2. Overview of the magnetic activity of the Sun in 2024. The figure shows from top to bottom: X-ray flare activity, relativistic proton flux, interplanetary magnetic field conditions, and solar wind speed. All of these parameters are measured near the Earth by the Geostationary Operational Environmental Satellites (GOES). The bottom line shows the geomagnetic activity indicator Kp (source GFZ Potsdam). Especially in May and early October SWX conditions were severe (red lines).

Figure 3 shows in detail the X-ray flares and geomagnetic activity in 2024. The figure indicates that the Sun was very active, especially on 10 - 11 May and 10 - 11 October, and as a result multiple advisories were issued during this timeframe.

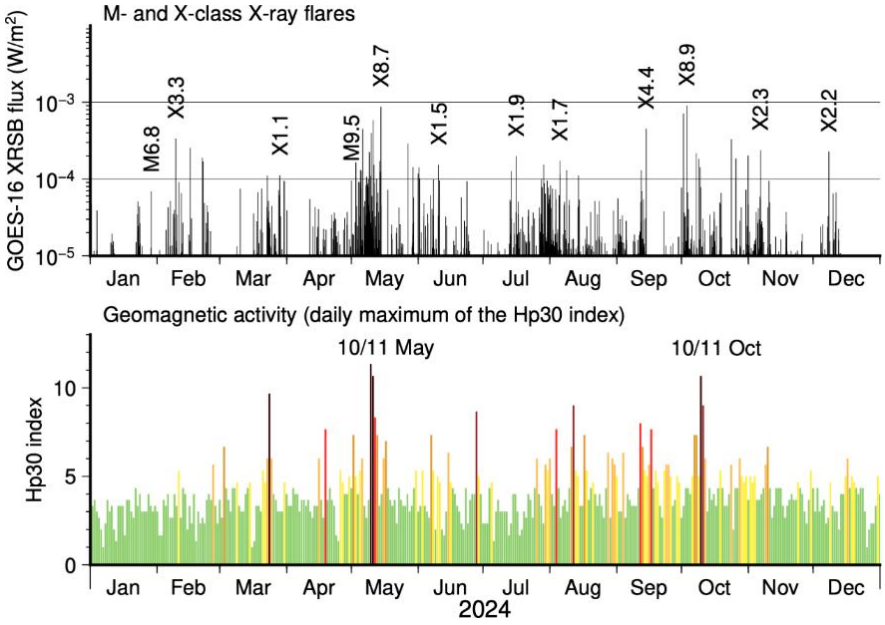

Figure 3. Detailed view of the strongest X-ray flares in 2024 (top) and Geomagnetic activity based on the daily maximum of the Hp30 index.

2.1 Overview of Advisories Issued Per SWXC Per Effect During the Reporting Period

The information presented in this section is based on analyses of the SWX advisories issued by the four global SWXCs, as received and analyzed by the Royal Netherlands Meteorological Institute (KNMI). KNMI is the air navigation service provider for the Netherlands and receives the advisories in its role as a random end-user.

In 2024, the SWXCs issued a total of 1040 advisories and 17 test advisories. Table 1 shows a breakdown of the number of advisories issued by each SWXC in 2024 for the different effects: Global Navigation Satellite System (GNSS), High Frequency Communications (HF COM) and Radiation (RAD) and for testing purposes. The number of events is a measure of how often the thresholds for these three parameters, GNSS, HF COM and RAD, were exceeded. Each event has an initial and a final advisory and updates if applicable. The number of test advisories is shown in round brackets.

Table 1. Number of advisories issued by the SWXCs in 2024 for the different effects and for testing purposes (in round brackets).

	GNSS	HF COM	RAD
SWPC	5	52 (3)	0
PECASUS	324 (2)	133 (1)	6 (1)
ACFJ	374 (2)	94 (1)	0 (1)
CRC	0 (2)	52	0 (4)
Number of Events	267	107	0

Table 1 shows a considerable variation in the number of advisories that are issued by the different SWXCs. It should be noted that the six RAD advisories were incorrectly issued on 24 March 2024. Therefore, it can be concluded that in 2024 it was not necessary to issue RAD advisories. In fact, since the start of operations in 2019, no RAD advisories were issued apart from those issued for test purposes.

The variation in GNSS advisories demonstrates the need to harmonize GNSS impact models between the SWXCs. This activity is ongoing in the SWXCCG. This applies to a lesser extent also for the HF COM advisories.

To facilitate an optimal use by end-users, there is a need to issue advisories with a minimal latency after a threshold has been exceeded. Figure 4 and Figure 5 show the latency of the GNSS and HF COM advisories issued by the four global SWXCs for the different SWX events (counts). In the future, reducing the latency will be important.

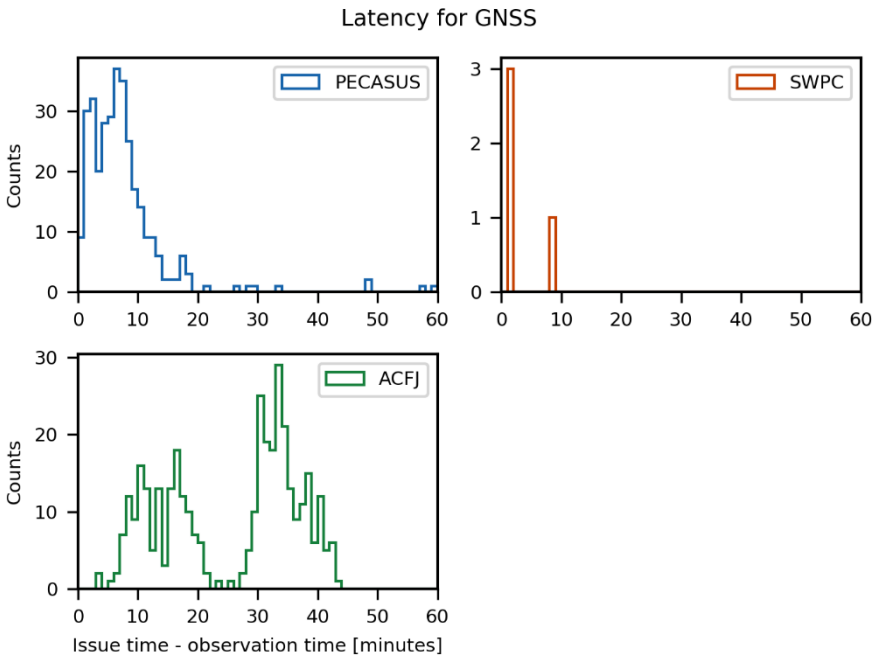

Figure 4. Latency of the GNSS advisories in minutes issued by three SWXCs for the various SWX events (counts). Note: CRC did not issue GNSS advisories.

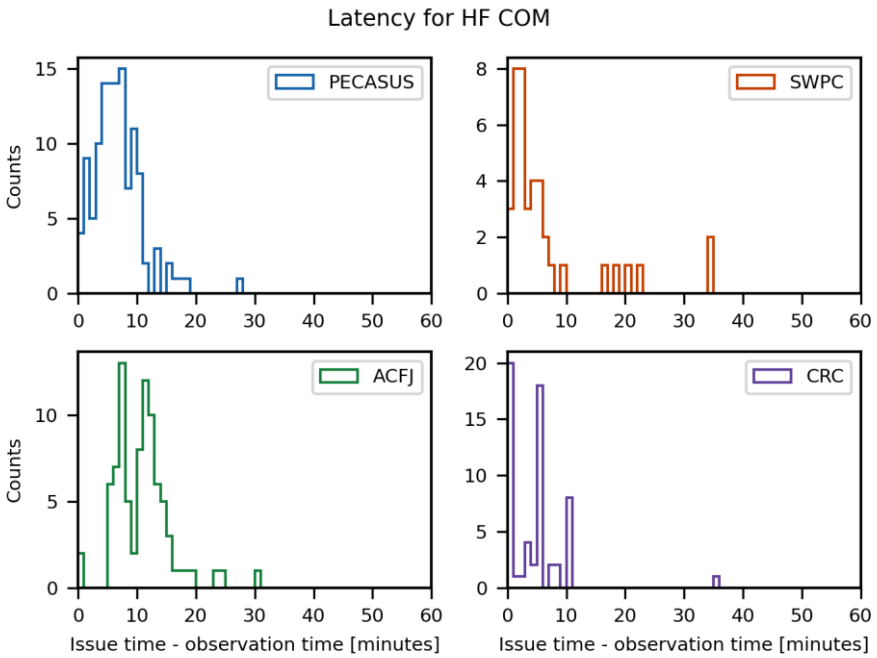

Figure 5. Latency of the HF COM advisories in minutes issued by the four SWXCs for the various SWX events (counts).

Figure 6 and Figure 7 show the impacted areas of the advisories issued by the different SWXCs. These differences can be attributed to the various sensor networks and models that are used by the different SWXCs as inputs to the advisories. To achieve more homogeneous coverage, data exchange of sensor and model data between the SWXCs is important. In the forthcoming years, data exchange between SWXCs can be facilitated through the WMO Information System (WIS) 2.0. This WMO system will also available for non-National Meteorological and Hydrological Service organizations although implementation will take several years (see Section 3). In the short term, these performance issues are being addressed in the SWXCCG.

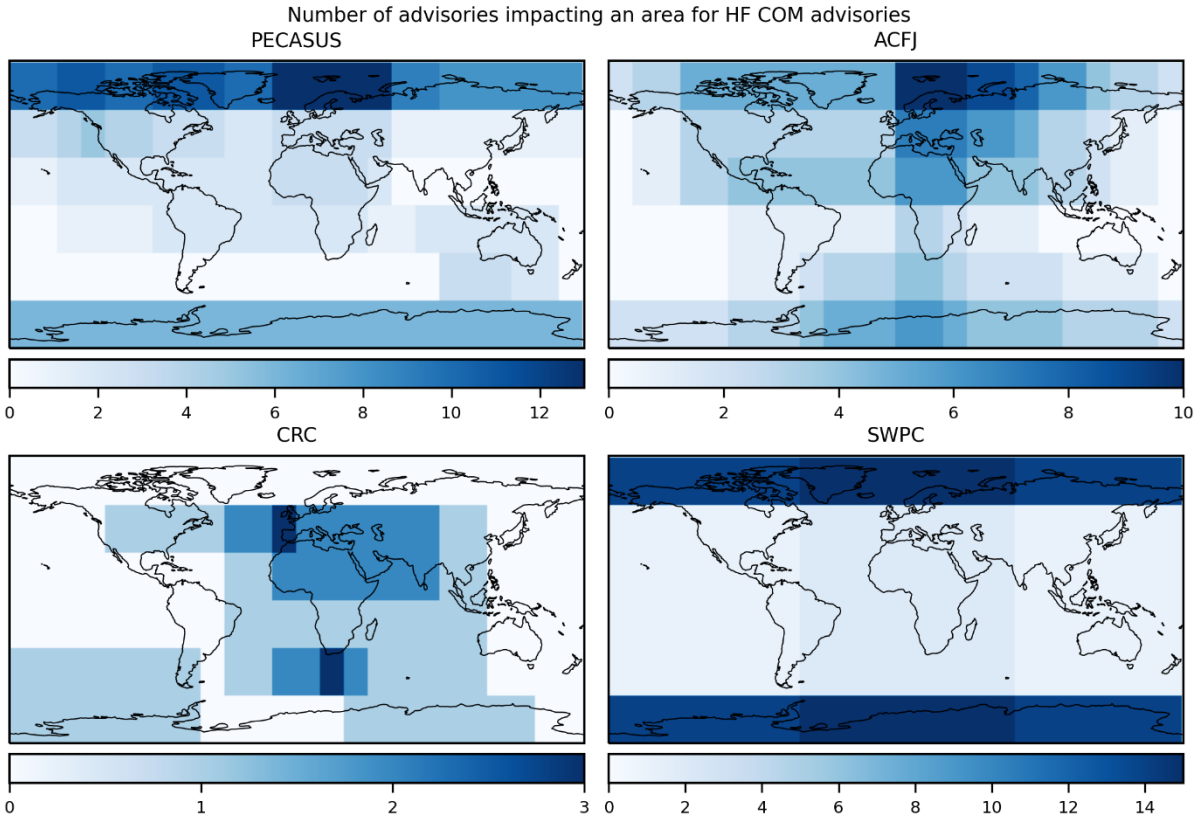

Figure 6. Impact areas of the HF COM advisories issued by the various SWXCs.

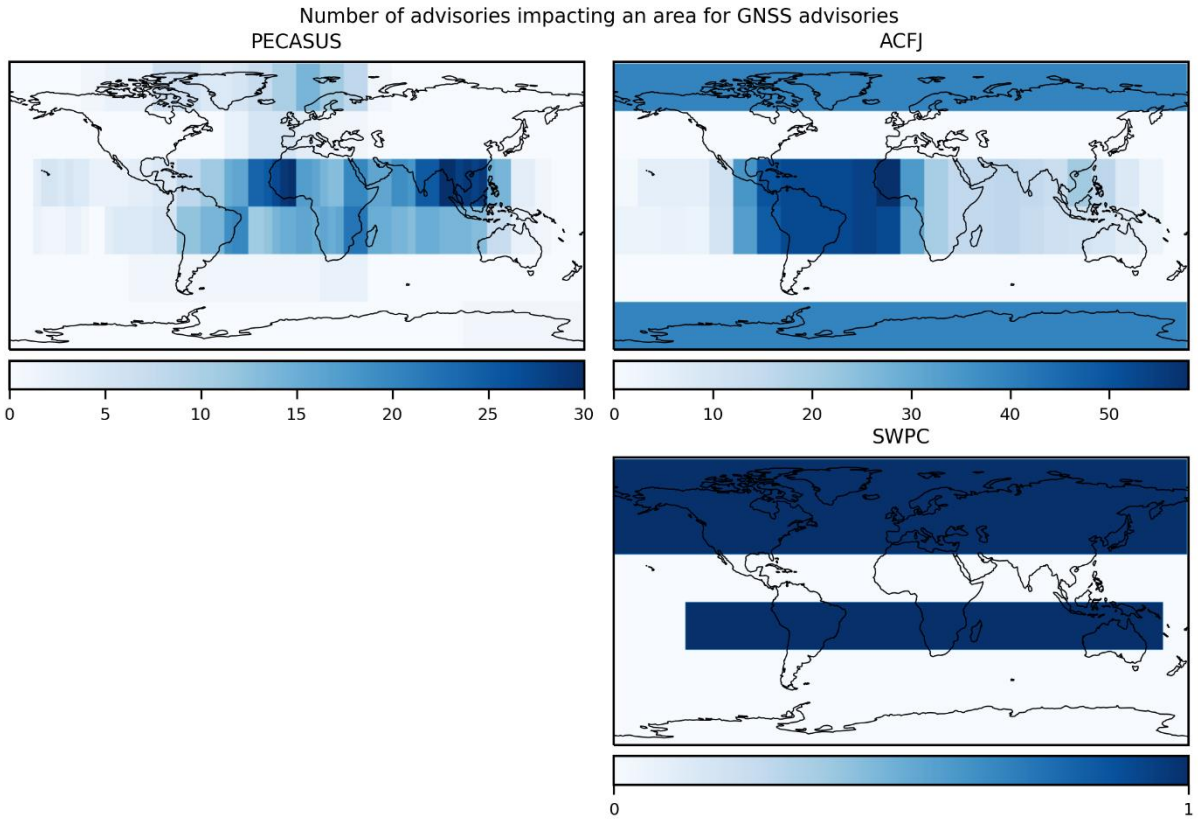

Figure 7. Impact areas of the advisories issued by the various SWXCs. Note: No GNSS impact areas shown for CRC as they did not issue GNSS advisories.

2.2 Findings on the Useability of Advisories

Advisory numbering

SWX advisories are part of the information stream to aviation end-users. Many end-users use automated processing of the information. Automated processing may be hampered by the following findings in 2024:

- Each SWX event is identified by an initial and a final advisory (NO FURTHER ADVISORIES). However, several final advisories have no replacement number (NR RPLC) and could be interpreted as a new isolated event by end-users.
- There are advisories for a new event that contain a replacement number that refers to a non-existing advisory.
- Three times an advisory number was used twice and on one occasion three times for different advisories that were subsequently issued for the same effect.
- Advisories for different effects (GNSS, HF COM) can have identical advisory numbers. When these effects occur simultaneously this can be confusing to the end-user.
- Test advisories are part of the SWX numbering sequence for a specific SWX effect. If test advisories are taken out of the processing stream, an end-user will interpret this as a missed advisory.
- When successive advisories are issued within a short time, the latest could be received first by the end-user. This may be perceived as a missing advisory by the end-user.

Advisory forecast information

Advisories are most valuable to end-users when they contain warnings for (possible) future SWX effects. However, the current Standards and Recommended Practices (SARPs) for SWIS in Annex 3 do not *require* forecast information. As a result, the SWX advisories contain, at minimum, nowcast information but in practice many advisories include forecast information. Table 2 shows the statistics of the 6-hour and 12-hour forecast information. The 18-hour and 24-hour forecast information is not shown because it contains less relevant information for the end-user and may require further refinement and harmonization of forecast models.

Forecast period	Detailed forecast	Not Expected forecast	Not Available forecast
6-hour forecast	82	112	846
12-hour forecast	46	128	866

Table 2. The SWXCs issued 1040 advisories in 2024. The table shows the number of advisories with a detailed forecast or an explicit statement that no further SWX impact was expected. The last column shows the number of advisories for which no forecast was available. The rows give the numbers for the 6-hour and 12-hour forecasts.

Free text in advisories remarks section

Next to the information contained in the mandatory section of the advisories, SWXCs can provide free text in the remarks (RMK) field of the advisories of up to 256 text characters. Of the 1040 advisories, 11 did not contain information in the RMK field (but did not have an entry “NIL”), 370 advisories contained up to 80-character text strings, 495 advisories contained text strings with character lengths between 100 – 199 characters and 123 advisories contained text strings with lengths in the range of 200 – 239 characters. In a number of cases, the information in the RMK field contains information that should be in the fixed fields of the advisories or is a copy of the fixed field information. The use of the RMK field varies considerably between SWXCs and sometimes very specific SWX information is provided that that may be difficult to understand by end-users like pilots and dispatchers. This finding will be addressed in the SWXCCG.

2.3 Results of Key Performance Indicators

KPIs measure the actual performance of the most important aspects of a service and set targets for improving a service. Currently, both timeliness and correct syntax are integrated into the KPIs. A minimal latency is important for informing end-users about ongoing events. A correct syntax is important for automatically and timely processing advisories.

This report is the first Management Report of the SWIS, so it combines performance information from all SWXCs. Both the KPIs and the Management Report template will evolve and will reflect continuous improvements over time. This first Management Report reflects the fact that solar activity is increasing toward the solar maximum. During future solar minimum, new KPIs may be more appropriate. For example, maintaining operational vigilance of a service during lower activity may require more testing and conducting exercises.

In principle, the KPIs should reflect the requirements for a service as detailed in Appendix A. For this first period, the applicable KPIs have been selected by the SWXCCG and are listed below:

- 90% of the advisories must be issued within 15 minutes after the time when the threshold for advisory issuance is met.
- 99% of the advisories that are issued shall have no syntax errors, no numbering errors and permit automated processing by end-users.

It may be clear from Figure 4 that the number of advisories per SWXC varies considerably. In general, 90% of the issued and checked advisories showed a latency of less than 15 minutes. The difference in the observed latency reported by ACFJ and PECASUS has been investigated in early 2025 and found to be caused by differing definitions of event onset. Harmonization activities are ongoing and are expected to cause the latency distributions to become more aligned. The low number of advisories issued by SWPC and CRC do not allow a consistent evaluation of the latencies.

The 99% KPI for the correct format and contents of the advisories implies that of the 1040 advisories that were issued about 1030 advisories were compliant. Of the non-compliances listed in Section 2.2, 11 advisories were found to be missing a “NR RPLC” for the end of an event. Taking into account the other findings, it was concluded that the correct format and contents of the KPI was not met in 2024.

Sub-teams within the SWXCCG are working to improve harmonization between SWXCs by developing procedural improvements that are expected to improve KPI compliance in 2025.

2.4 Operational Continuity of the Service

For any operational service, continuity is of vital importance. At the time of the audit of the various candidate global SWXCs, this "continuity" requirement was captured in the so-called reliability[2], availability[3] and maintainability[4] requirements for each SWXC. These requirements are listed in Appendix A.

The operations concept that has been implemented has, by design, a high-level of built-in redundancy such that an (almost) 100% continuity of SWIS is ensured. The four global SWXCs perform SWX monitoring and forecasting in two week shifts with one SWXC serving as the ODC and the others serving as the PBC, the SBC and the MOC.

The SWXCs have a rigorous back-up process, which will occur if the ODC is unable to perform its functions. For unscheduled handovers, the ODC will pass the service to the PBC. This back-up process is intended to ensure that the users receive continuity of service. However, maintaining a record of unscheduled handovers provides a useful record in case users experience issues during these unscheduled handovers.

On 1 April 2024 at 18:52 Coordinated Universal Time (UTC) there was an unscheduled handover from PECASUS to SWPC. X-ray data were missing when PECASUS was the ODC, so operations were transferred to the PBC, SWPC, where X-ray data were available. Once the X-ray data were once again available at PECASUS, even though they were still the ODC, it was decided not to transfer operations back to PECASUS because SWPC would become ODC on 2 April at 8:00 UTC according to the operations schedule. This was the only unscheduled handover event in 2024.

3. FUTURE DEVELOPMENTS AND SERVICE IMPROVEMENTS

Over the coming years, the SWIS will further develop. Toward the end of this decade a Technical Review of the SWIS is anticipated, including a reassessment of the optimal number of global and regional SWXCs. The Technical Review is planned to be complete by 2027. However, that deadline may be extended because the SWIS is not yet fully implemented (the regional SWXC will not be integrated into the operational SWIS until November 2025 and there is no global cost recovery mechanism for the SWIS) and the planned changes to the information provided by the SWIS in 2025 and 2027 may complicate completing the Technical Review.

Despite these difficulties, service improvements are discussed at various levels.

The SWXCCG coordinates activities between the different SWXCs, advises the ICAO METP WG-MOG SWX WS on improvements to Annex 3 and PANS-MET provisions, introduces improvements and changes in the SWIS and advisories as approved by the WG-MOG SWX WS. The SWXCCG also

[2] Reliability. The probability of a system or system element performing its intended function under stated conditions without failure for a given period of time.
[3] Availability. The probability that a repairable system or system element is operational at a given point in time under a given set of environment conditions.
[4] Maintainability. The probability that a system or system element can be repaired in a defined environment within a specified period of time.

maintains the operating procedures for the development of advisories; also known as “the Cookbook” because it contains the “recipe” or “steps” needed to follow when generating the SWX advisories. The SWXCCG also evaluates the satellite data, ground-based data and model data required to produce advisories. This includes harmonization of models and data sets used by all SWXCs as well as recommendation of thresholds when moderate and severe impacts are expected.

The METP WG-MOG SWX WS prepares AMDs to Annex 3 and PANS-MET. In 2024, the focus was on preparing AMD 83 to Annex 3 and AMD 1 to the PANS-MET to be reviewed and endorsed by the 233rd session of the ICAO Air Navigation Commission in November 2026 and subsequently by the 241st session of the ICAO Council in May 2027. The proposed changes are based on end-user feedback, advice by the SWXCCG on implementation and by members/advisors of the METP WG-MOG SWX WS including experts and representatives of ICAO, the International Federation of Air Line Pilots Associations, the International Air Transport Association, the Federal Aviation Administration and the WMO. Examples of the proposed changes include the introduction of a SWX outlook for +12 to +48 hours and changing the advisory forecast resolution from +6, +12, +18 and +24 hours to +3, +6, +9 and +12 hours to better address flight planning requirements and forecast model capability. The METP WG-MOG SWX WS also proposed various changes in the ICAO *Manual on Space Weather information in support of International Air Navigation* (Doc 10100, [Reference: RD-2]) for the RAD advisories to improve relevance (noting that as of the publication of this report no valid RAD advisory has been issued). Some longer-term improvements have already been identified and will be included in AMD 84 to Annex 3 and AMD 2 to the PANS-MET.

The WMO plays an important role in SWX development in general. It can be foreseen that in the future, SWXCs could resemble meteorological services as many requirements are transferable. For example, Figure 6 and Figure 7 show that the impact areas of advisories do show a dependence on the issuing SWXC. Data exchange and standardization will lead to harmonization and centre-independent services. The ET-SWx of the WMO’s INFCOM has a work program for the coming years addressing multiple items required to improve SWX in general. SWIS will benefit from these activities because these will facilitate data exchange and harmonization of the SWXCs. The ET-SWx workplan [Reference: RD-3] addresses standards and best-practices for observations, data and models, competency frameworks and inclusion of SWX in the WMO Integrated Global Observing System and the new WIS 2.0 for integrated observation networks and data exchange, respectively. An important input for improvements is end-user feedback. Individual SWXCs have organized end-user feedback sessions and surveys (see Section 4). Additionally, some larger-scale SWX related user-engagement events were organized recently such as the Tabletop exercise in November 2023 conducted by the European Aviation Crisis Coordination Cell (EACCC) of the European Organisation for the Safety of Air Navigation (EUROCONTROL) that included extended participation of end-users. Following the exercise, a concluding workshop was held in June 2024 resulting in recommendations and feedback that were communicated to the METP WG-MOG SWX WS, the SWXCCG, participating airlines, ICAO and IATA. The actions defined focus on improving impact studies for SWX, harmonizing services and stimulating the use of SWX advisories by the aviation sector.

4. SWXC ACTIVITIES IN 2024

This section consists of brief reports, one from each SWXC, that include concise SWXC-specific information like technical/procedural developments; changes in observations and models; matters

related to quality management system (QMS); competency, training and education activities; outreach activities; and relevant research.

ACFJ Report

ACFJ was ODC during the following two-week (14-day) periods in 2024: 09 - 23 January, 05 - 19 March, 30 April - 14 May, 25 June - 9 July, 20 August - 3 September, 15 - 29 October and 10 - 24 December.

In 2024, ACFJ held regular coordination meetings in February, April, June, September and November, and held multiple engagements by email to coordinate responses to the METP WG-MOG SWX WS and the SWXCCG.

Technical/procedural developments include:

- In preparation for a scheduled outage of the SWPC GOES data products, ACFJ developed a contingency plan ensuring uninterrupted operation of services to aviation. This included identification of alternative sources of GOES Solar UltraViolet (UV) Imager, X-ray, and energetic particle data, and a 12-hour hand-off between Australia and Canada monitoring riometer data feeds for absorption signatures. Between April and June, SWPC experienced two planned and one unplanned outages of the GOES data service. ACFJ was not ODC during the outages.
- ACFJ – Australia noted difficulties in accessing the external webpages due to excess load during the 10 - 11 May 2024 SWX event. They have since doubled the resources available to support the external webpages, thus mitigating the load problem.
- ACFJ was the ODC during the 10 - 11 May 2024 SWX event. Following the event, the consortium held an after-action meeting to evaluate advisories issued during the event, and a review of internal standard operating procedures, communication between SWXCs during the event and impacts reported from key stakeholders.
    - User feedback indicated there was some confusion in the sudden drop from severe HF COM conditions to quiet conditions without a transition to moderate levels. ACFJ evaluated the conditions and determined that the data supported this transition (i.e., there was a sudden drop in solar proton flux causing polar cap absorption) and concluded that increased user education is necessary. Some of the confusion could have been caused by 20-hour event durations reported in the advisory forecast information and more accurate estimation of event duration was identified as a future research topic.
    - User feedback also indicated confusion around ending one advisory for HF COM shortwave fadeout while there was still an ongoing HF COM absorption event in progress. This feedback and discussion were passed to SWXCCG Sub-Team 3 to consider for documentation updates.
    - An advisory was mistakenly sent with a “TEST” status that led to skipping of one unused advisory number in the sequencing. Communication between countries was identified as the source of the error and improvements have been discussed.

  - It is worth noting that the 10 - 11 May 2024 event did have a significant increase in workload within ACFJ. This event could be considered for future exercises and tests within all SWXCs.

- ACFJ-Canada experienced an outage of its primary automated monitoring system for two hours on 30 August, and successfully switched to its secondary system, minimizing total system outage to 35 minutes. Conditions were monitored manually during the outage and no SWX advisories were required to be issued during this time.

Changes in observations and models include:

- ACFJ-Canada began installation of a Canada-wide scintillation receiver network comprised of 32 instruments. Installation is expected to be completed by the end of the 2026 field season.
- ACFJ has noted several examples where harmonization between global SWXCs was not demonstrated and has taken the following actions:
  - Lack of harmonization between ACFJ and PECASUS was reported by KMNI at the 2024 European Space Weather Workshop (as reported above). In December 2024, ACFJ and PECASUS began harmonization efforts, which have since been moved to SWXCCG Sub-Team 15.
  - Lack of harmonization between ACFJ and the three other SWXCs was noted by ACFJ and brought up to the METP WG-MOG SWX WS. ACFJ is now leading harmonization activities through SWXCCG Sub-Team 8 and co-leading SWXCCG Sub-Team 15.
- ACFJ-Canada updated its real-time Kp-proxy, used to monitor auroral absorption, based on K-index values calculated at its Ottawa, St-Johns, and Victoria geomagnetic observatories, all of which contribute to the Kp index.
- ACFJ-France has continued to maintain and improve the GNSS advisory service. Collecte Localisation Satellite (CLS) has ensured global coverage of scintillation successfully through the year and have overhauled the GNSS station network adding new stations at points of interest and removing obsolete stations. European Satellite Service Provider (ESSP) have streamlined and fixed issues in the GNSS advisory validation code and worked with other ACFJ partners to identify these issues and to fix them swiftly.
- ACFJ has begun the conversation for introducing polygons in our regular meetings. Through these meetings and work progressed by each country, ACFJ has been able to initiate the discussions in the SWXCCG meeting on polygons and how to apply a consistent approach.
- ACFJ-Japan – WASAVIES (RAD model) has had some issues that have been investigated and looking to apply some bug fixes.
- ACFJ-Australia – Upgraded seven ionosondes across Australia and Antarctica to improve data quality and reliability of the SWX observation network.

Quality management aspects (e.g., internal audits, evaluation incidents) include:

- ACFJ-Australia is progressing through an internal audit process to evaluate the service provided by each section to ensure high standards.
- ACFJ-France has recently provided an updated internal contingency plan and ran a successful contingency test focussed on the scenario of a lack of Total Electron Content (TEC) data availability. A test of the resilience of the GNSS advisory validation system was also

successfully carried out simulating a sudden forced restart of the system. Before each ODC, ACFJ-France also tests the ability to disseminate advisories to partners.

- As part of an internal audit within ACFJ-France (CLS), it was found that certain aspects of their work were quite individualised, with technical notes and procedures not necessarily shared all the time. They therefore set-up a shared workspace within the team, in which all documents related to the ICAO project are shared.

Competency, training and education activities include:

- Due to the high level of activity in 2024, ACFJ did not schedule an annual exercise in 2024. Procedures were instead evaluated during the 10 - 11 May 2024 after-action discussion.
- ACFJ members engaged in educational activities through attendance of conference activities including the European Space Weather Workshop and United States' Space Weather Workshop.
- ACFJ-Australia has developed training modules and courses for both the ACFJ Scientist and ACFJ Duty Forecaster roles. All current staff have completed this training, and we are continually updating and improving the courses for future staff. Also, we are looking to implement a workplace observation to support the competency process.
- Five new forecasters have received SWX training at ACFJ-France (ESSP) during 2024. The training process involves a series of online presentations and tests, and one-to-one training regarding the SWX data, code and advisory validation with the SWX service manager.

End-user engagement includes:

- ACFJ-Canada conducted external stakeholder engagement with NAV CANADA through several virtual meetings.
- ACFJ-Canada presented Transport Canada's Civil Aviation Daily Occurrence Reporting System (CADORS; https://wwwapps.tc.gc.ca/saf-sec-sur/2/cadors-screaq/m.aspx?lang=eng) as a source of SWX impacts to civil aviation. Impacts to GNSS are usually found by filtering for messages reporting difficulties using Localiser Performance with Vertical Guidance.
- ACFJ-Australia attended the ICAO Asia Pacific Ministerial Conference on Civil Aviation, and gave a webinar on SWX, SWX advisories, SWX impacts and the need for feedback.
- ACFJ-Australia continues to engage with domestic customers in the Aviation Industry Services Working Group. These meetings allow for user feedback on the SWIS.
- ACFJ-Australia has provided SWX presentations to the Asia-Pacific Meteorology sub-group meeting through the Meteorology Seminar to engage with international users and ensure the up-to-date knowledge on the ICAO SWIS.
- ACFJ have discussed the service with the French Civil Aviation authority, DGAC, via online meetings who have provided some feedback to ICAO regarding the lack of harmonisation in the forecast and the high frequency of GNSS advisories. ACFJ are aiming to increase this engagement and to act upon the feedback via contributions to the Sub-Team 15 on the topic of GNSS advisory harmonisation.
- ACFJ-Japan has been communicating with aviation users about the situations and impacts of SWX events and continues to report the initial results in the METP WG-MOG SWX WS meetings.

Relevant research includes:

- ACFJ-Canada performed the research in several areas with applications to SWX services for civil aviation:
    - GNSS phase scintillation forecast model and event duration based on an evaluation of sigma-phi scintillation and magnetic data in Canada,
    - ionospheric scintillation activity in Canada and its influence on the Wide Area Augmentation System, and
    - development of an auroral absorption model characterized by the AE index.
- ACFJ-France contributed an analysis of the GNSS advisories disseminated during the 10 - 11 May 2024 SWX event. The detailed discussion of this was supplied to other SWXCs and discussed during ACFJ meetings. An analysis of the GNSS advisories that ACFJ would have disseminated during the 10 - 11 October 2024 event, if ACFJ were ODC, was shared with PECASUS for comparison, and to help identify differences in the GNSS advisories the respective global SWXC disseminate.

CRC Report

The CRC, a global SWXC, operates with teams in Beijing, China and Moscow, Russia. Alongside global international data sources, the teams access instruments from the FengYun-series (FY), the Geostationary Operational Meteorological Satellite-series (GOMS), and the Ionosfera-series satellites.

The FY satellite series excels in SWX monitoring, with eight satellites (four Low Earth Orbit, four Geostationary Earth Orbit) currently operational, carrying 34 SWX payloads. These provide data on charged particles, geomagnetic fields, auroral and ionospheric images, and solar Extreme UV (EUV) images. FY-4C, scheduled for launch in 2025, will include three new instruments: MUSI (Multiband Ionospheric UV Spectrum Imager) for 131–162 nm UV emissions, SEUVI (Solar Extreme-UV Imager) for solar monitoring in four EUV bands, and SXUS (Solar X-ray and EUV Irradiance Sensor). FY-3H, also launching in 2025, will carry an Ionospheric Photometer and Wide-field Auroral Imager.

The Elektro-L (GOMS) series comprises geostationary satellites, with Elektro-L N2/3/4 (GOMS-3/4/5) operational and Elektro-L N5 (GOMS-6) planned for 2025. These satellites feature space environment suites, including particle counters (SKL, GALS) and X-ray radiation flux meters (DIR). The Elektro-M series, set to replace Elektro-L starting in 2030, will introduce new equipment[5].

The Ionozond project includes four sun-synchronous satellites: Ionosfera and Zond-M. Equipped with solar telescopes, coronagraphs, radiation meters, 150/400 MHz transmitters, ionospheric sounders, and cosmic ray spectrometers, two Ionosfera satellites are operational, with two more planned by 2027. Zond-M is expected to launch in 2025.

The CRC's supporting organizations—National Center for Space Weather (CMA), Institute of Applied Geophysics (Roshydromet), and Aviation Meteorological Service (CAAC)—enhanced operational software. For example, Fengyun-Space, a cloud-based platform for SWX analysis and forecasting, is now operational, aiding forecasters with artificial intelligence-enhanced tools. CMA has also

[5] https://space.oscar.wmo.int/satellites/view/electro_l_n5

deployed CMA-SWAPS (CMA-Space Weather Assimilation and Prediction System), a “Sun-to-Earth” SWX numerical model framework. At the International Association of Geodesy (IAG,) a machine-learning-based method for predicting planetary geomagnetic indices, refined with extensive retrospective data, is now in use.

The CRC promotes training for aviation meteorologists and supports ICAO and global SWX initiatives, engaging with bodies like the United Nations’ Committee on the Peaceful Uses of Outer Space (e.g., sixty-second Session, 3 - 14 February 2025, Scientific and Technical Subcommittee) and PT/EAST of METP.

The CRC fosters global collaboration. Since 2022, SWX has been a topic at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)-CMA Technical Workshop. Both NCSW and IAG participate in several working groups of the Coordination Group for Meteorological Satellites.

PECASUS Report

During 2024, the PECASUS consortium upgraded and streamlined its practices and tools related to SWX monitoring, advisory issuance routines and service quality management. The dashboards that the duty officers use for activity monitoring have been updated with new functionalities and the editing tools creating the advisories have been upgraded with more versatile syntax error checking. The work of duty officers has been facilitated with incremental improvements to internal monitoring and alerting systems (e.g., on data outages). In addition, upgrades to current systems and preparatory work for the Annex 3 future amendments have been done, particularly in support of transition to using polygons.

PECASUS partners have improved their observation systems with new measurement sites for better coverage of GNSS and HF COM services. The tools refining raw data to products have been upgraded with unified visualization and error flagging to facilitate event detection and fluent decision making in the context of advisory issuance. Some smoothing procedures to keep the number of GNSS advisory issuance on a sensible level have been developed. Together with the other global SWXCs, PECASUS has conducted studies on accuracy of RAD models in describing the impacts by Solar Proton Events. Inside PECASUS, some arrangements have been made to use additional supporting observations and modelling to validate the primary RAD model results.

The consortium has arranged tailored training sessions for its new duty officers and the supporting team of SWX experts. In addition, SWX training for external communities, including the aviation sector and contingency authorities, have been organized. Collaboration with the EACCC under EUROCONTROL has been continued by post-analysis of the user feedback collected in the EACCC Space Weather Tabletop exercise organized in November 2023. Bi-lateral meetings with European airlines to promote and collect feedback about the ICAO services provided have been arranged. Particularly useful insights have been received from discussions with KLM Royal Dutch Airlines and with the dispatching center at the Schiphol airport.

PECASUS scientists chaired sessions and gave presentations about their data analysis tools and models both during the United States’ Space Weather Workshop (April 2024) and the European Space Weather Week (November 2024). The United Kingdom Met Office chaired during the United States’ Space Weather Workshop a session on Ionosphere and Thermosphere Research and

Applications. During the European Space Weather Week, the Solar-Terrestrial Centre of Excellence (STCE) chaired a session on Space Weather Service Validation and the United Kingdom Met Office on Space Weather Impacts during the strong May 2024 SWX storm. STCE and the Finnish Meteorological Institute (FMI) provided daily SWX forecasts during two days of the week. As an example of a smaller scientific gathering, ICAO SWX services with their future upgrading needs have been addressed in a workshop arranged at FMI in September 2024 under the European Union Project ALBATROS (https://www.albatros-horizon.eu/).

SWPC Report

In 2024, the SWPC achieved several major milestones in its quality management efforts, including successful initial certification to International Organization for Standardization (ISO) 9001:2015 on 19 April. Additionally, seven internal audits and four quarterly management reviews were conducted, resulting in zero operational non-conformities.

The Technology Division further enhanced operational capabilities through advancements. Forecasters received Version 4.0 of the ICAO Advisories user interface (Mercury) in late 2024, following pre-deployment training in September. This updated interface introduced significant graphics and user experience improvements, streamlining the production and monitoring of SWX advisories. The Technology Division also made substantial progress in updating the software to generate ICAO advisories in Traditional Alphanumeric Code and ICAO Meteorological Information Exchange Model formats. These updates aim to align with ICAO AMD 81 to Annex 3 requirements, including integrating geospatial JavaScript Object Notation model data for GNSS and radiation phenomena. Enhancements now allow for polygon-shaped advisory areas (5–7 points) and reflect geographic and textual changes to be implemented in the November 2025 update. While initial training and user feedback have been completed, additional work is ongoing to incorporate input and validate the revised advisory formats ahead of the planned operational deployment.

The Science Division contributed to advisory improvements through applied research and model refinement. At the 2024 American Geophysical Union Fall Meeting, a SWPC scientist presented a poster titled *Comparative Analysis of Aviation Radiation Models During Solar Energetic Particle Events*. Scientists also evaluated whether high frequency radio disruptions—particularly those influenced by maximum usable frequency depressions—would be better modeled by the Whole Atmosphere Model-Ionosphere Plasmasphere Electrodynamics Model or the existing Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model. Additionally, observed differences in the D-Region Absorption Prediction model (shortwave fade) model output among international SWXCs suggest the possibility of variation in model implementation.

Beyond internal efforts, SWPC engaged with the aviation sector and the broader emergency management community. In collaboration with the Science and Technology Policy Institute, aviation stakeholders participated in interviews to evaluate the R, S, and G SWX Scales. The feedback will inform recommendations for scale improvements to serve end-users better. The SWPC Service Coordinator delivered presentations at the Federal Aviation Administration's Technical Exchange Meeting and an IBM-hosted Space Weather Seminar focused on aviation support. SWPC also participated in a United States Government Space Weather Tabletop Exercise, emphasizing its preparedness and commitment to interagency coordination.

SANSA Report

Technical/procedural developments include:

- All technical and procedural elements related to the SWXC have been developed in accordance with the QMS and aligned with the Business Continuity Plan.
- An operational shift system has been established to ensure uninterrupted 24/7 service delivery.

Changes in observations and models include:

- Additional ground-based infrastructure has been deployed to enhance observation capabilities across the African region.

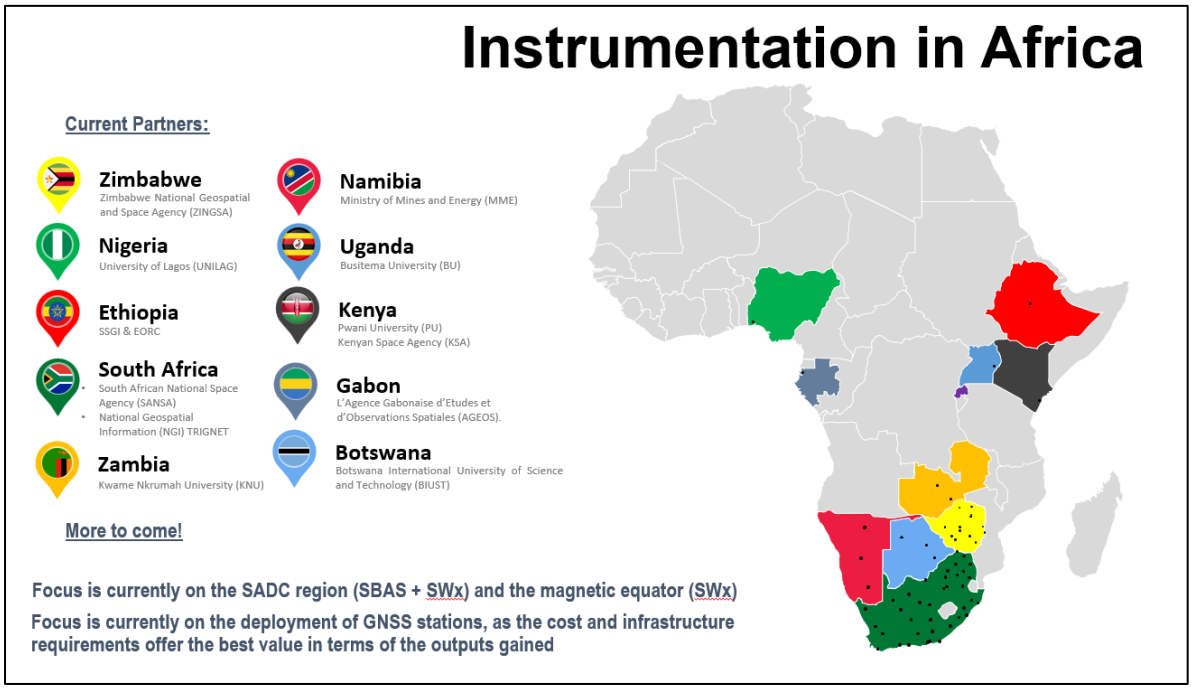

Figure 8. A map showing the GNSS receivers in Africa.

- Six additional GNSS receivers are planned: Tanzania, Ghana, South Sudan, Egypt, DRC, and Ivory Coast.
- The three-dimensional electron density model is now fully operational within the SWXC.

QMS matters include:

- The SWXC maintains its ISO 9001:2015 certification.
- The second surveillance audit was successfully completed with no major non-conformances.

Competency includes:

- SANSA has trained eight SWX forecasters through both internal and external programs. A formal assessment process has confirmed their competency.
- Three additional trainee forecasters have been recruited, undergone internal training, and integrated into the operational shift system.

- An independent service provider conducted a comprehensive skills audit for the organization, highlighting the expertise and competencies within the team.

Training, education, and outreach activities include:

- Based on the skills audit, customer feedback, and QMS audit outcomes, personalized development plans are being formulated to enhance the SWXC's capabilities.
- Internal SWX forecaster training for the trainee forecasters.
- In collaboration with the Air Traffic Navigation Services Training Academy, SANSA is developing a SWX curriculum tailored for aviation personnel. A pilot training session was conducted with national aviation professionals to assess competency levels.

Relevant research includes:

- SANSA participated and presented the SWX research in international and national workshops/conferences. Research was carried out to develop the three-dimensional reconstruction model (https://doi.org/10.1016/j.asr.2024.02.014), which is operational and gives predictions for the next three days. Based on the operational near-real-time ionosonde measurements, an absence of high-frequency echoes from ionosondes during the 23 - 25 April 2023 geomagnetic storm was investigated to ask what happened (https://doi.org/10.1029/2023JA032277). A high total electron content was observed over Zambia (https://doi.org/10.1016/j.asr.2025.03.023) and other locations in the northern part of South Africa. These high TEC values occurred regardless of the geomagnetic storm.

Appendix A Requirements for SWXCs

The following ICAO qualification requirements were used for the SWXC selection in 2017 [RD-4].

INSTITUTIONAL criteria
Experience as a designated national space weather information provider
A Quality Management System (Annex 3 – Meteorological Service for International Air Navigation)
Appropriate qualifications of the personnel and an ongoing competency and training program (WMO-No 49, WMO-No 258)
Adherence to all applicable data rights
Procedures to liaison with aviation decision-makers and gather feedback on the space weather information service
Procedures for coordination with other space weather information providers.
A source of funding and adequate level of funding to provide the space weather information service for a period of at least 3 years
OPERATIONAL criteria
24/7 operational capability
A system reliability of 99.9 percent with no single failure exceeding 90 minutes in a 24-hour period.
A system availability of 98.0 percent with no single outage exceeding 4 hours in a 1-year period.
A system maintainability of 95.0 percent for a 2-hour interval.
TECHNICAL criteria
Ability to provide the space weather information service, both near real-time and forecast information, as defined in the draft SARPs for Amendment 78 of ICAO Annex 3 — Meteorological Service for International Air Navigation
Ability to access observations (own observations ad received from other space weather providers) of: i. Coronal mass ejections and high-speed streams; ii. Geomagnetic storms; iii. Solar radiation storms; iv. Solar flares; v. Solar radio bursts; and vi. Ionospheric activity
Ability to produce near real-time and forecast information with the space weather information providers for adjacent areas of responsibility a necessary
Ability to conduct forecast verification and provide verification statistics as service performance indicators
COMMUNICATION/DISSEMINATION criteria
Ability to provide the space weather information service to aviation decision-makers, as defined in the draft SARPs for Amendment 78 of ICAO Annex 3 — *Meteorological Service for International Air Navigation*
Ability to provide a communications system and infrastructure that supports the availability, maintainability, and reliability criteria.
Ability to provide the space weather information service via the following means of dissemination: i. ICAO Aeronautical Fixed Service (AFS); ii. World Area Forecast System Internet File Service (WIFS); iii. Secure Aviation Data Information Service (SADIS); iv. Regional OPMET centres