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OVERVIEW OF THE SPACE WEATHER IMPACT ON THE NAVIGATION AND COMMUNICATION SYSTEMS

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Abstract: This article summarizes and analyzes the space weather impact on the Earth´s surface, aviation – especially navigation and communication aids, satellite functions ensuring communication, and GPS function. Forecasting the geomagnetic storms, solar radiation storms, radio blackouts, X-ray flux, and others is difficult due to the high variability of the space weather conditions and sun activity. It can change every hour and the exact space weather conditions and the impact on aviation for the future are hard to predict. This article shows some predictions and historical data regarding space weather activity, where the stated values were collected from the NOAA page. The article states the daily maximums or the maximums of predicted phenomena activity. Because of the complexity and the facts mentioned above, the historical data and predictions show the summary and most important phenomena of the day. Topics dealt with similar topics regarding space weather activity are the following: *"GNSS ambiguity resolution with ratio and fixed failure ratio tests for long baseline network RTK under the ionospheric activity"* discusses GNSS failure under ionospheric activity [1]. *"Impulsive disturbances of the geomagnetic field as a cause of induced currents of electric power lines"* – how can affect the space weather activity on the Earth´s surface, environment and what is the highest risk of GCIs [2] *"Semi-annual, annual and Universal Time variations in the magnetosphere and in geomagnetic activity: 1. Geomagnetic data"* – the article studies the semi-annual variation in geomagnetic activity, and compares geomagnetic data variation. [3] *"Geomagnetic solar flare effects: a review"* – the article discusses the Sfe rapid variation and the intensity of produced radiation during Solar flare events. [4] The above-mentioned topics are directly focused on space weather and were published in the JSWSC journal. The last chapter in this article is a conclusion that consists of and mentions some information about the used alternative methods when a GPS lapse occurs. Even though there are some alternate systems, but still using satellite-based navigation and communication aids is still the first option, and space weather events highly affect the systems and are a big hazard for aviation.

Keywords: aviation, geomagnetic storm, radio blackouts, solar radiation storms, space weather, X-ray flares

1. SPACE WEATHER

The space weather refers to many variable conditions in space, on the sun that can influence the performance, reliability, and accuracy of the used technologies on the Earth, especially in aviation.
It has a great impact on the Earth´s climate and magnetosphere, electric power transmission, GPS function, HF radio communication, satellite communication, and satellite drag.

The space weather affects not only the above-mentioned, but also creates phenomena like – aurora, coronal holes, coronal mass ejections, galactic cosmic rays, ionospheric scintillation, radiation belts, solar EUV irradiance, solar flares, which can cause radio blackouts; solar radiation storms and winds, sunspots or solar cycle and total electron content.

NOAA describes, that: "In the aviation sector, space weather poses a threat through communication, navigation, and radiation concerns." [5]
It can highly impact A/C communication systems by the increasing radiation due to the ionization in the ionosphere. This can attenuate HF radio waves (3-30 MHz). The communication system

malfunction caused by radiation concerns affects mostly the oceanic area, where sending and receiving information is really important. The ionospheric disturbances disrupt GNSS and GPS signals and limit communication and navigation accuracy.

The radiation has two kinds of threats:

1. technical – airplane electronic equipment
2. human factor - crew and passenger's health in high FL.

The types of space weather phenomena affect different technologies on Earth. For example, solar flares can produce strong X-rays that block or degrade the HF radio waves used for communication. This event is known as Radio Blackout Storms.

The energetic particles block radio communication at high latitudes during solar radiation storms.

Geomagnetic storms modify the GPS and GNSS signals and in this way affect the radio navigation systems causing lower or degraded accuracy. [5]

NOAA in short describes the space phenomena as follows: "Space weather can occur anywhere from the surface of the sun to the surface of the Earth. As a space weather storm leaves the sun, it passes through the corona and into the solar wind. When it reaches Earth, it energizes Earth´s magnetosphere and accelerates electrons and protons down to Earth´s magnetic field lines where they collide with the atmosphere and ionosphere, particularly at high latitudes." [6]

There are three types of space weather storms which can mostly affect the aviation navigation aids and communication systems:

1. radio blackouts
2. solar radiation storms
3. geomagnetic storms.

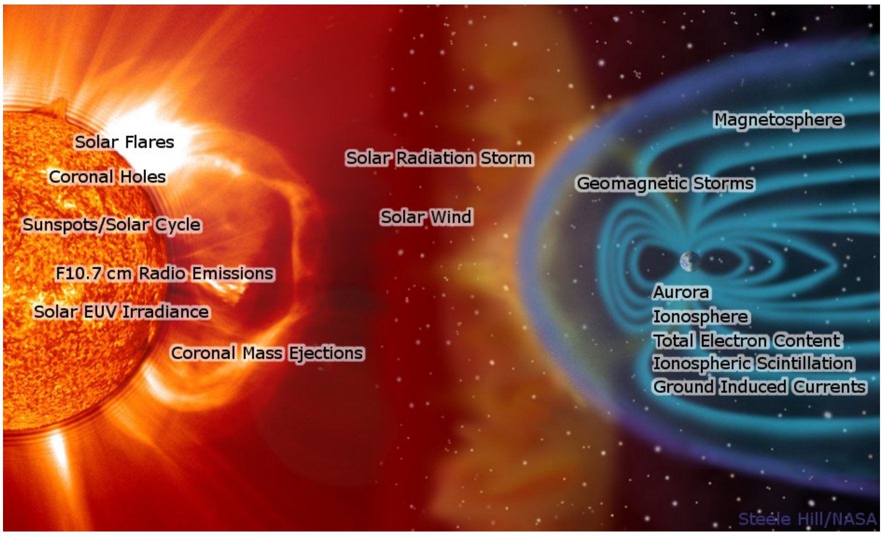

Figure 1 Space weather phenomena [6]

Figure 1 describes the space weather phenomena and their nexus to the Earth.

Solar flares are large eruptions of electromagnetic radiation from the Sun. It can take from minutes to hours. It is a sudden outburst of electromagnetic energy from the Sun, which travels at the speed of light. On the sunlight side of the Earth, in the lower levels of the ionosphere, it causes ionization due to the increased level of X-ray and EUV (extreme ultraviolet radiation). The strong solar flares cause HF radio communication block. In normal conditions, HF radio waves support communication by refraction via the upper layers of the ionosphere. When strong solar flares occur, ionization is produced in the lower layers of the ionosphere, which are denser – D-layer. The radio waves interacting with electrons lose energy due to the frequent collisions in the higher-density D-layer environment and then cause HF radio signal degradation. The signals are completely absorbed. Primarily impact the 3-30 MHz signals. Solar flares occur at the active regions of the Sun, associated with **sunspots** (strong magnetic fields) (see Figure 2). [7]

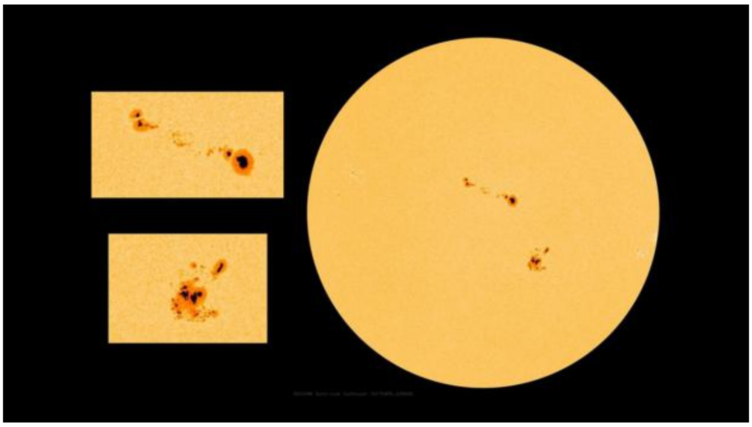

Figure 2 Sunspots [7]

When the magnetic fields reach a point of instability, then they release energy, which includes electromagnetic radiation – observed as solar flares. Solar flare intensity is classified based on the peak emission:
- 0.1 – 0.8 nm spectral band = soft X-rays. [6]

The X-ray flux levels are divided into 5 categories based on the intensity:

1. "A" level – starting at 10^{-8} W/m^2
2. "B" level – ten times higher; ≥ 10^{-7} W/m^2
3. "C" level – 10^{-6} W/m^2
4. "M" flares – 10^{-5} W/m^2
5. "X" level – 10^{-4} W/m^2.

Based on the above values the **radio blackouts** are directly related to the flare´s maximum peak. The forecast probability is given as an X-ray flux level and radio blackout level based on the X-ray intensity and level.
The radio blackouts are caused by the X-ray and extreme ultraviolet radiation from solar flares. Primarily affects HF (High Frequency) communication, where the frequency is from 3 to 30 MHz. Fading and diminished reception may affect VHF (Very High Frequency – 30 – 300 MHz) or higher frequencies. [8]
Radio blackouts are the most common space weather events that can affect aviation and our planet.
Table 1 describes the correlation between radio blackouts and solar flares, nominal energy flux, and designated severity description. The table is from the NOAA space weather page. [8]

Table 1 Correlation between radio blackout and solar flares, nominal energy flux and severity description [6]

Radio Blackout	X-ray flares	Flux (W/m^2)	Severity Description
R1	M1	0.00001	Minor
R2	M5	0.00005	Moderate
R3	X1	0.0001	Strong
R4	X10	0.001	Severe
R5	X20	0.002	Extreme

The value R1 has a minor impact and the physical measure for X-ray flares is M1. It can cause low-frequency navigation signal degradation for brief intervals. The impact on HF radio communication is weak and can cause minor degradation, with only an occasional loss of radio communication.

R2 has a moderate impact and causes a limited blackout of HF radio communication and loss of radio communication for tens of minutes. Also, the degradation of low-frequency navigation signals is for tens of minutes.
R3 has a strong impact with an X1 physical measure X-ray flares. It can cause low-frequency navigation signal degradation for an hour, and also a wide area HF radio communication blackout for an hour.
R4 has a severe intense and causes minor disruptions of satellite navigation, and outages of low-frequency navigation signals. The HF radio communication blackout can last for one to two hours, loss of HF radio contact.
R5 is classified as extreme and causes a complete HF radio blackout (on the sunlit side of the Earth) for many hours, with no radio contact during the en-route flights. The low-frequency navigation signals have huge outages for many hours. Aviation can cause a loss in positioning or many errors. [9]

Coronal holes look like a dark area in the Sun's corona in EUV (extreme ultraviolet) and soft X-ray solar images. (see Figure 3)

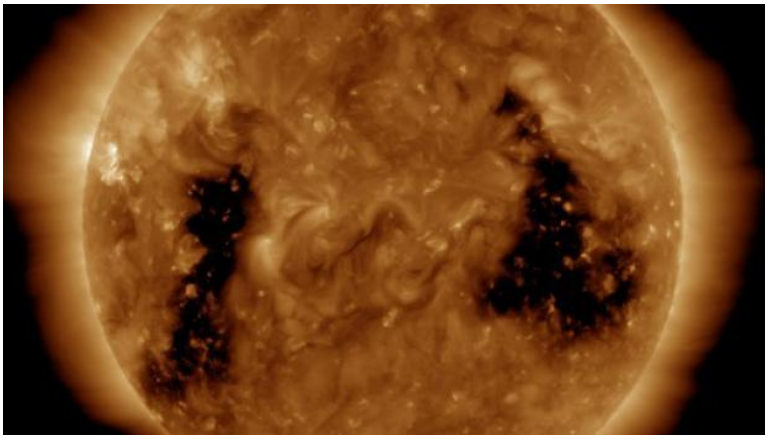

Figure 3 Coronal holes [10]

They are less dense and cooler than the surrounding plasma. These areas are regions of open, unipolar magnetic fields, which allow the easier **solar wind** to escape into space. [10]

A geomagnetic storm occurs when a very efficient exchange of energy from the solar wind into the space environment exists. The largest storms are associated with CMEs – solar coronal mass ejections. Here a billion tons of plasma from the sun enter the Earth. The geomagnetic storm is given by the geomagnetic disturbance index – Kp index. This index gives two currents:

1. a ring of westward current - the measurement of this is the disturbance storm time index (Dst), and characterizes the size of a storm
2. a field-aligned current – auroral currents also called the auroral electrojets.

Together with the G-Scale (Geomagnetic Storm) the Kp index is used to describe the space weather situation, which can disrupt the important systems used in aviation, like GPS and GNSS.
Table 2 shows the scale and Kp index with the effect of geomagnetic storms. [9]

Table 2 The geomagnetic storm´s impact on the aviation [9]

Category		**Geomagnetic Storms** Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	The duration of the event will influence the severity of the effects		
G5	Extreme	Power system: Widespread voltage control problems and protective system problems can occur, and some	Kp = 9	4 per cycle (4 days per

		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.).		cycle)
G4	Severe	Power system: 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 is sporadic, satellite navigation is degraded for hours, low-frequency radio navigation is 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)
G3	Strong	Power system: Voltage corrections may be required, and 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)
G2	Moderate	Power system: High-latitude power systems may experience voltage alarms, and 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)
G1	Minor	Power system: 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)

A **solar radiation storm** often causes a coronal mass ejection (CMEs) and associated solar flares. NOAA categorizes a solar radiation storm into 5 categories:

1. S1 – minor impact
2. S2 – moderate impact
3. S3 – strong impact
4. S4 – severe impact
5. S5 – extreme impact (see Table 3) [9]

Table 3 The solar radiation storm's impact on aviation [9]

Category		**Solar Radiation Storms** Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor			
S5	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; and 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.	10^5	Fewer than 1 per cycle
S4	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.	10^4	3 per cycle
S3	Strong	**Biological:** Radiation hazard avoidance is 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 panels are likely. **Other systems:** Degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S2	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 are possible.	10^2	25 per cycle

		Other systems: Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.		
S1	Minor	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

2. SPACE WEATHER IMPACT ON TECHNOLOGICAL VULNERABILITY

Based on the orbit, and service application there are three classifications for satellite technologies:

1. GEO – geostationary Earth orbit
2. MEO – medium Earth orbit
3. LEO – low Earth orbit.

Table 4 describes the satellite system classification based on the usage and orbital layouts.

Table 4 Correlation between radio blackout and solar flares, nominal energy flux and severity description [5]

Orbit	Altitude in km	Use
GEO	36 786 km	Telecommunication and weather (GEOS)
MEO	2 000 – 30 000 km	Navigation and communications satellites (GPS, GNSS)
LEO	200 – 2 000 km	Data communication, high-resolution Earth resources imagery (from ISS – International Space Station)

Figure 4 describes the location conjoint with the thermosphere, ionosphere, and magnetosphere, and the impact of the space weather on the satellite system.

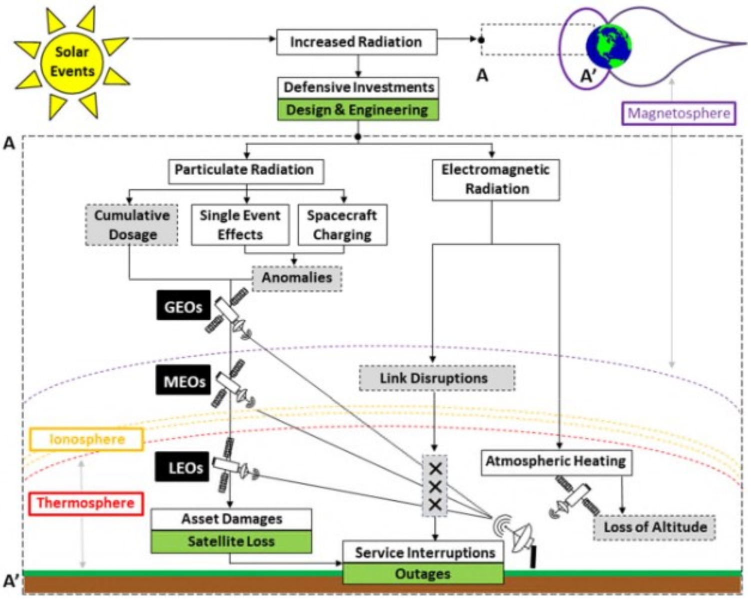

Figure 4 Technological vulnerability [5]

3. SPACE WEATHER CONDITION OVERVIEW IN DATA

Monitoring and forecasting the space weather conditions is in three main important categories:

- radio communication – monitoring the solar X-ray flux and radio blackouts, and making the D region absorption prediction

- GPS – preparing a 1 - 4 day prediction of solar wind structures and CMEs that cause geomagnetic storms. It is monitored by WSA-Enlil large-scale, physics-based model

- aviation – monitoring and predicting the proton flux (by GOES satellites), and D region absorption prediction.

Figure 5 describes the NOAA space weather overview, orientated on the solar X-ray flux, solar proton flux, and geomagnetic activity.

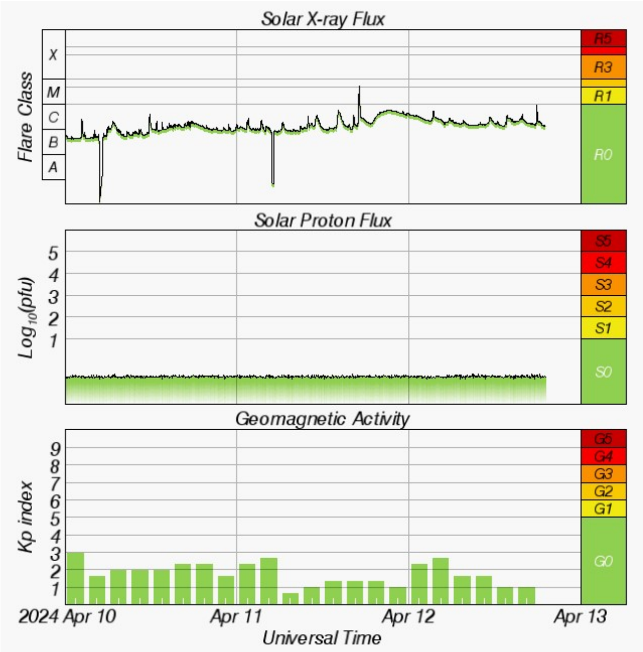

Figure 5 Space weather overview [11]

Figure 5 describes the observed and monitored values regarding the Kp index, where the geomagnetic activity these days was negligible. The Kp index was maximally 3 and the geomagnetic storm scale has only G0 values, not even a minor impact. Only a flare-class minor impact was observed, where the radio blackouts scale was R1 – minor impact on the HF radio communication (weak degradation on the sunlit side of Earth), and the navigation signals were degraded for a brief interval.

For GPS communication monitoring and prediction NOAA uses the WSA-ENLIL system. The historical data and forecast data are shown in the following pictures (see Figure 6). In this article, Figure 6 defines only a 4-day data (from the 7-day forecast). The plasma density (r2N/cm3) and the radial velocity (km/s) are measured.

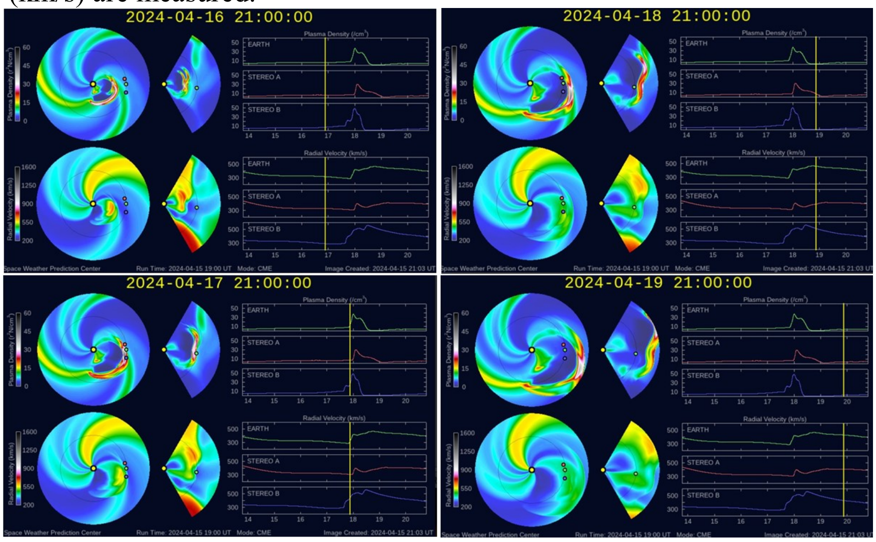

Figure 6 WSA-ENLIL Solar wind prediction [12]

For aviation, the sphere is also a prediction of a 5-minute average integral proton flux observation on the primary GOES satellite. The proton event warning forecast is provided in two timelines:

- warning of the expected onset of a proton event
- warning of the expected persistence of a proton event, which is in progress. The warning period is given in timelines valid from – valid to. The ≥ 10 MeV values march the S-scale (Solar Radiation Storm) thresholds. The thresholds are 10, 100, 1 000, 10 000, and 100 000 pfu (proton flux unit).

Figure 7 shows the GEOS Proton Flux 5-minute data for 7-day values.

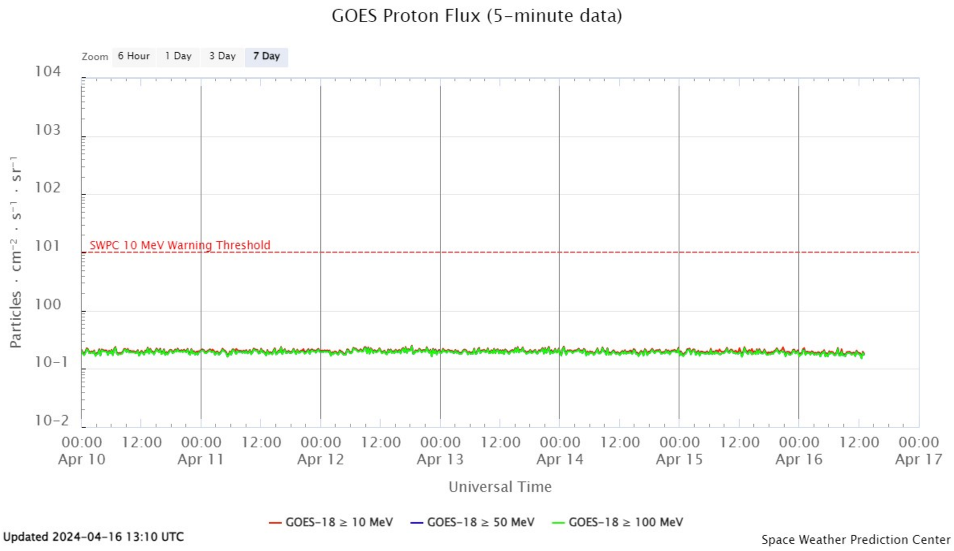

Figure 7 GOES Proton Flux (5-minute data) [13]

NOAA also publishes a geophysical alert, where the format and the content of the alert are the following (see Figure 8):

```
:Product: Geophysical Alert Message wwv.txt
:Issued: 2024 Apr 16 0905 UTC
# Prepared by the US Dept. of Commerce, NOAA, Space Weather Prediction Center
#
#          Geophysical Alert Message
#
Solar-terrestrial indices for 15 April follow.
Solar flux 192 and estimated planetary A-index 8.
The estimated planetary K-index at 0900 UTC on 16 April was 4.33.

Space weather for the past 24 hours has been minor.
Radio blackouts reaching the R1 level occurred.

Space weather for the next 24 hours is predicted to be minor.
Radio blackouts reaching the R1 level are likely.
```

Figure 8 Geophysical alert [14]

The first half of April daily maximum activity (significant activities and alerts in April) of the space weather conditions (geomagnetic storms - G values, solar radiation storms – S values, radio blackouts – R values, and solar wind speed) is shown in Table 5.

The first half of April is considered from the 1st of April to 21st of April.

April 11 alert – Space Weather Message Code: ALTTP4; Serial Number: 629; Issue Time: 2024 Apr 11 1714UTC. The alert was about the IV Radio Emission type at the beginning of 1659 UTC. The NOAA description was "Type IV emissions occur in association with major eruption on the sun and are typically associated with strong coronal mass ejections and solar radiation storms." [15]

April 21 alert – Type II Radio Emission. Beginning Time: 2024 Apr 21 2209UTC. Estimated Velocity: 278 km/s. The NOAA Descriptions: "Type II emission occurs in association with eruption on the sun and typically indicates a coronal mass ejection is associated with a flare event." [15]

The space weather message code is ALTTP2; and the serial Number: is 1284.

Table 5 shows the significant space weather activity related to G scales and R scales associated with X-ray flux.

Table 5 Daily maximum of space weather conditions in April – significant activities [16]

Day in April/Space Weather Conditions	*G scales (maximum intensity)*	*R scales (maximum intensity)*	*X-ray flux (maximum intensity)*	*K-index (maximum intensity)*
11.04.2024	-	R2 - moderate	M5.4	-
16.04.2024	G2 - moderate	-	-	5
19.04.2024	G3 - strong	-	-	7

The historical data of space weather alerts and warnings with greater impact occurred on March 18 – 24. are stated in the next lines [15] and summarized in Table 6:

1. Space Weather Message Code: ALTXMF
   Serial Number: 347; Issue Time: 2024 Mar 18 1918UTC
   The alert concerns the X-ray flux which exceeded M5 and the Radio Blackouts scale was moderate – R2. (See Table 6)
   The potential impact for the HF radio communication was moderate, which can cause a limited blackout and low-frequency navigation signal degradation for tens of minutes in the impacted area.
2. Space Weather Message Code: ALTXMF
   Serial Number: 348; Issue Time: 2024 MAR 20 0735UTC
   Here is an alert about the radio blackouts with scales R2 – moderate. The next alert – summarization alert – with serial number 208 and code SUMXM5 – warns against the X-ray flux exceeding M5 (M7.4). [15]
3. Space Weather Message Code: ALTXMF
   Serial Number: 349; Issue Time: 2024 Mar 23 0119UTC
   The alert was about the X-ray flux exceeding 5; and a radio blackout with a value of R2 – moderate.
   Also on Mar 23, with a serial number 1283 to message code ALTTP2, NOAA published an alert – type II radio emission. The beginning time was 0109 UTC and the estimated velocity was 791 km/s. The II-type emission occurred in association with eruptions on the sun indicating a coronal mass ejection with a flare event.
   On 23 Mar NOAA published the summary message with code SUMX01, and serial number 140. The content related to the X-ray event exceeded X1 with a beginning time of 0058 UTC, and a maximum time of 0133 UTC. The predicted end time was 0222 UTC.
   X-ray class: X1.1
   Radio Blackouts: R3 – strong.
   The potential impact was an HF radio communication issue for about an hour.
   The next summary message for the same day consisted of information about the duration – 66 minutes, and peak flux 240 sfu. In the description, they stated, " A 10 cm radio burst indicates that the electromagnetic burst associated with a solar flare at the 10 cm wavelength was double or greater than the initial 10 cm radio background." In association with a solar flare, it could indicate a significant radio noise and could cause some interference for navigation aids including radar, GPS, and satellite communication.
   On the same day, the geomagnetic storms scale category was G2 – moderate. [15]
4. On March 24 there was an active geomagnetic storm activity and the scale changed for all day from G2 moderate to G4 severe. There was also a sudden geomagnetic impulse and deviation of 377 nT.

Space Weather Message Code: ALTK08
Serial Number: 30; Issue Time: 2024 Mar 24 1629UTC
The alert regarded the geomagnetic K.index of 8, 9. It was predicted that the threshold may be reached at 1628UTC, and the synoptic period 1500 – 1800 UTC. There was an active warning, and the geomagnetic storms category was G4 – severe.
The potential impact was severe – possible widespread voltage control problems, protective systems mistakes, drag on low earth orbit satellites, tracking and orientation problems, GPS degradation for hours, and HF radio communication blackouts. [15]

5. At March 28 there was an R2 - moderate daily maximum radio blackouts, and the X-ray flux exceeded value M5. The space weather message with the SUMXM5 code actualizes the information:
   Space Weather Message Code: SUMXM5
   Serial Number: 211; Issue Time: 2024 Mar 28 1633UTC
   Summary: X.ray Event exceeded M5. The beginning time was predicted at 1540 UTC, the maximum time at 1556 UTC, and the end time at 1603 UTC.
   X-ray Class: M6.1. NOAA Scale: R2 – moderate.
   The next message with serial number 212 and code SUMXM5 shows the X-ray flux exceeding - from M6.1 to X1.1. [15]
6. March 30 Space Weather situation - based on the Space Weather Message Code: SUMXM5 and with the Serial Number 213. It is a continuing message to the previous day based on the continuing space weather event.
   X-ray Class: M9.4. The NOAA scales remained on R2 – moderate. The K-index was 4. [15]

Table 6 Historical data in March 2024 of space weather alerts and warnings [15, 16]

Day and month of 2024 / Space Weather condition	*Radio Blackouts (daily maximum)*	*X-rays flux (daily maximum)*	*Geomagnetic Storms (daily maximum)*	*Geomagnetic K-index (daily maximum)*
18 March	R2 – moderate	M6.7 (from message with code SUMXM5; serial number 207)	-	-
20 March	R2 – moderate	M7.4 (serial number 208; SUMXM5)	-	-
23 March	R3 – strong	X1.1 (from the message with code SUMX01)	G2 - moderate	5
24 March	-	-	G4 - severe	8,9
28 March	R2 – moderate	X1.1 (serial number 212; code SUMXM5)	-	-
30 March	R2 – moderate	M9.4 (from serial number 213; code SUMXM5)	-	4

4. CONCLUSION

The article is an overview of the space weather's most intense activity in March and the first half of April regarding the geomagnetic storm, solar radiation storm, radio blackout, K-index, and X-ray flux activity. The paper analyses these phenomena and activities associated with the impact on navigation and communication aids that are used in the aviation sector. The most practical and historically actual data are mentioned in Chapter 3.

Chapter 3 discusses the space weather conditions in the actual 2 spring months in 2024 – March and April. Based on the analysis, it is obvious that predicting and forecasting the space weather conditions for the next few days is hard. Due to the sun's activity and intensity variability, the space weather activity is also variable and daily changing many times. It can analyze the historic maximas per day, and the phenomena impact on the Earth´s surface, navigation aids, and communication aids.

In Chapter 3, Figures 5 and 6 show the historical maximum activities, geostorm intensity, radio blackouts, and impact on the aviation and satellite systems. There is a huge variability between the daily activities of radio blackouts, geomagnetic storms, X-ray flux, and solar radiation storm intensity.

The space weather prediction center publishes alerts, and warning messages related to space weather activities – like G scales, S cales, R scales, X-rays, and K-index intensity.

The highest intensity in March was on 23 and 24 March, when the geomagnetic storm intensity reached G4, which is a severe activity with a huge impact on the navigation and communication aids in aviation. These intensities cause a severe lapse and system degradation for hours, which has a negative impact on aviation.

NOAA is the main company that deals with space weather monitoring, forecasting, and describing. Except for NOAA, there are other pages, that also provide information about the space weather – ADVACAM (has integrated radiation monitors into the NASAs and ESAs spacecraft and satellites); SOLCAST § DNV company (they allow free access to the API Toolkit for live, forecast and also historical solar irradiance data or PV power data); PECASUS for ICAO (it is one of the 4 global centers providing space weather monitoring and advisories according to ICAO regulations); and the other three services (mentioned at PECASUS) are NOAA (mentioned in this article), ACFJ (formed by Australia, Canada, France and Japan), and CRC (formed by China and Russia).

The main two Space agencies are NASA and ESA.

The conclusion is, that the aviation sector is highly vulnerable to space weather activities. In a situation where geomagnetic activities cause a huge lapse in navigation and communication during flight, the effective solution is the alternate procedure – using indoor real-time location system (tracking and positioning), ILS, and MLS systems primarily, DME, and VOR. The indoor location technologies also include systems like LIDAR (Light Detection and Ranging), UHF RFID, and VLC. System Lidar is mostly used in the aviation sector regarding UAVs.

5. REFERECNCES

[1] Silva C.M., Setti Júnior P.T., Slves D.B.M., Souza E.M. "*GNSS ambiguity resolution with ratio and fixed failure ratio tests for long baseline network RTK under the ionospheric activity"*. Journal of Atmospheric and Solar-Terrestrial Physics. Volume 202, June 2020, 105256. Elsevier. https://doi.org/10.1016/j.jastp.2020.105256

[2] Belakhovsky V., et. al. "*Impulsive disturbances of the geomagnetic field as a cause of induced currents of electric power lines"*. J. Space Weather Space Clim., Volume 9, 2019. https://doi.org/10.1051/swsc/2019015

[3] Lockwood M., et. al. *"Semi-annual, annual and Universal Time variations in the magnetosphere and in geomagnetic activity: 1. Geomagnetic data"*. J. Space Weather Space Clim., Volume 10, 2020, 23. https://doi.org/10.1051/swsc/2020023

[4] Juan José Curto. *"Geomagnetic solar flare effects: a review*". J. Space Weather Space Clim., Volume 10, 2020, 27. https://doi.org/10.1051/swsc/2020027

[5] NOAA, Abt Associates Inc. 6130 Executive Boulevard, Rockville, MD 20852. Final Report: "Customer Needs and Requirements for Space Weather Products and Services". March 2019.

Online:
https://www.swpc.noaa.gov/sites/default/files/images/FINAL%20SWPC%20User%20Needs%20Report-1.pdf
[6] NOAA – Space Weather Prediction Centre: Space Weather Phenomena. Online: https://www.swpc.noaa.gov/phenomena
[7] NOAA – Space Weather Prediction Centre: Sunspots/Solar Cycle. Online: https://www.swpc.noaa.gov/phenomena/sunspotssolar-cycle
[8] NOAA – Space Weather Prediction Centre: Solar Flares (Radio Blackouts) Online: https://www.swpc.noaa.gov/phenomena/solar-flares-radio-blackouts
[9] NOAA – Space Weather Prediction Centre: NOAA Space Weather Scales. Online: https://www.swpc.noaa.gov/noaa-scales-explanation
[10]NOAA – Space Weather Prediction Centre: Coronal Holes. Online: https://www.swpc.noaa.gov/phenomena/coronal-holes
[11] NOAA – Space Weather Prediction Centre: Radio Communication Dashboard. Online: https://www.swpc.noaa.gov/communities/radio-communications
[12] NOAA – Space Weather Prediction Centre: Global Positioning System (GPS) Community Dashboard. Online: https://www.swpc.noaa.gov/communities/global-positioning-system-gps-community-dashboard
[13]NOAA – Space Weather Prediction Centre: GOES Proton Flux. Online: https://www.swpc.noaa.gov/products/goes-proton-flux
[14] NOAA – Space Weather Prediction Centre: Geophysical Alert – WWV Text. Online: https://www.swpc.noaa.gov/products/geophysical-alert-wwv-text
[15] NOAA – Space Weather Prediction Centre: Alerts, Watches and Warnings. Online: https://www.swpc.noaa.gov/products/alerts-watches-and-warnings
[16] NOAA – Space Weather Prediction Centre Online: https://www.swpc.noaa.gov/#

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