# SPACE WEATHER
## RECOMMENDATIONS GUIDE IN MEXICO

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# Space Weather Recommendations Guide in Mexico

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# FOREWORD

We live in the era large dependence on technology and global interconnectedness has exposed us to new challenges. Space Weather (SWx) is emerging as a critical factor that could impact key infrastructure and systems. On May 10, 2024, a severe geomagnetic storm, the most intense event since 2003, affected the planet.

Space exploration has given us knowledge of the Sun's influence on Earth’s environment. At the same time, with the increasing complexity and expansion of our power grids, communication systems, and satellites, it is necessary to understand and mitigate the risks associated with solar storms and other SWx related events.

In an increasingly interconnected world, effective risk management related to SWx becomes imperative to safeguard key infrastructure and ensure the continuity of operations. We hope this guide serves as a valuable resource and as a call to action, reminding us of the importance of preparedness and collaboration in an environment where prevention is the key to ensuring a resilient future.

This Guide to Space Weather Recommendations in Mexico aims to make visible the study and understanding of solar phenomena in our country and thereby contribute to the development of a series of methodological instruments whose purpose is to reduce the risk of disaster linked to extreme events caused by the SWx, contributing to the increase in resilience in Mexico in the face of their possible occurrence.

# INTRODUCTION

In recent decades, the effects of solar storms showed the importance of studies on SWx (González-Esparza, 2022).

In the context of this Guide, SWx will be understood as the harmful effects on modern technological systems caused by phenomena that occur on the Sun, in the interplanetary medium, geomagnetic field, Earth's atmosphere, and ionosphere (Koskinen *et al*., 2001; Cannon, 2013; Sergeeva, 2022).

SWx disturbances are irregular conditions that represent danger for both space-based and ground-based technological systems. An extreme SWx event can severely impact a country or regional technological infrastructure and critical services, affecting activities and processes essential for everyday life of society.

Consequently, SWx events ARE AN issue of international importance and national security since they can affect satellites, global positioning and navigation systems, communications, transportation, energy transmission and distribution networks.

On June 3, 2014, as part of a series of amendments to the General Civil Protection Law, the definition of "Astronomical Phenomenon" was included in the natural hazard list. It is understood as "Events or processes in outer space, including solar storms and meteors. Some of these phenomena interact with the Earth causing disturbances both in the atmosphere and on the Earth's surface, including magnetic storms and the impacts of meteorites."

On the other hand, in October 2014, the Mexican Space Weather Service (SCiESMEX) was created at the Universidad Nacional Autónoma de México with the tasks of studying, monitoring and alerting the corresponding authorities on the effects of SWx in our region. In 2016, with the support of the National Council of Humanities, Sciences and Technologies (CONAHCYT), the National Space Weather Laboratory (LANCE) was established with the aims to develop the scientific infrastructure, monitor, register and store SWx data in different regions of the country.

In 2017, the first comprehensive studies on the disturbances registered in Mexico during global SWx events were reported. To provide an example, the solar storm of September 2017 caused problems in radio communications in the Caribbean area. These studies showed that even moderate SWx events affect Mexico (González-Esparza *et al*., 2018; De la Luz *et al*., 2018). During the geomagnetic storm of May 10, 2024, the effects in the region were measured by the instrumental networks of LANCE registering variations in cosmic ray fluxes, in the regional geomagnetic and ionospheric parameter variations as well as the response of the national electric system (González-Esparza *et al*., 2024).

This guide suggests an action plan to mitigate the SWx social and economic impacts within Mexico's national territory. The plan focuses on three strategic objectives, on which the collaboration of various governmental entities and academia is proposed.

# ACRONYMS AND ABBREVIATIONS

**CENAPRED:** National Center for Disaster Prevention

**CNPC:** National Civil Protection Coordination

**CONAHCYT:** National Council of Humanities, Sciences and Technologies

**DOF:** Official Gazette of the Federation

**GIR:** Comprehensive Risk Management

**GUIDE:** Space Weather Recommendations Guide in Mexico

**ICAO:** United Nations International Civil Aviation Organization

**IFT:** Federal Telecommunications Institute

**ITU-R:** Radiocommunication Sector of the International Telecommunication Union

**LANCE:** National Space Weather Laboratory of the Institute of Geophysics Unidad Michoacán of the Universidad Nacional Autónoma de México and the Autonomous University of Nuevo León

**SCiESMEX:** Mexican Space Weather Service

**SINAPROC:** National Civil Protection System

**SWx :** Space Weather

**UNAM:** Universidad Nacional Autónoma de México

# LIST OF AGENCIES AND ENTITIES OF THE FEDERAL PUBLIC ADMINISTRATION

This document was prepared by the Space Weather Group in Mexico formed with the following agencies and entities of the Federal Public Administration (All the acronyms are given in Spanish):

**AEM:** Mexican Space Agency

**AFAC:** Federal Civil Aviation Agency

**CENACE:** National Energy Control Center

**CENAPRED:** National Center for Disaster Prevention

**CFE:** Federal Electricity Commission

**CNPC:** National Civil Protection Coordination

**IFT:** Federal Institute of Telecommunications

**IPN:** National Polytechnic Institute

**LANCE:** National Space Weather Laboratory

**SEDENA:** Secretariat of National Defense

**SICT:** Secretary of Infrastructure, Communications and Transportation

**SEMAR:** Secretary of the Navy

**SENEAM:** Navigation Services in the Mexican Airspace

**SSA:** Ministry of Health

**UNAM:** Universidad Nacional Autónoma de México

# CURRENT STATE DIAGNOSTICS AND ANALYSIS

Large solar storms have the potential to cause significant perturbations in the Earth's space environment, including the geomagnetic field, ionosphere and thermosphere. These disturbances impact the operation and reliability of critical technological systems: satellites, telecommunication systems, Global Navigation Satellite Systems (GNSS), air and maritime navigation, radars, electrical power distribution, etc. The magnitude of these effects emphasizes the importance of considering SWx as a matter of national security and sovereignty and making its study in Mexico unavoidable.

Key actions have been identified to address this need, such as Mexico developing its own instrumentation network to register the effects of SWx in different regions of the country. This will facilitate real-time monitoring and create a historical data archive for strategic decisions under severe or extreme events.

In 2017, the development of the observational instrument networks began with the support of CONAHCYT projects. Still, socioeconomic studies that quantify the potential damages from SWx events in Mexico lack depth.

The technological vulnerability of the already mentioned satellite systems, radio communications, different GNSS (GPS, GLONASS, GALILEO, BDS-II, and augmentation systems), etc., makes prominent the risks that a severe solar storm represents for the Mexican territory becoming an issue of safety and prosperity of the country. Mexico has already implemented the General Civil Protection Law that addresses the hazards associated with SWx.

It is imperative that strategic sectors, including telecommunications, transportation, energy, financial sector, health, and water supply, are well informed about the measures required to be taken in case of an extreme SWx event. These measurements should be aligned is aligned with the need to improve the distribution of information at all levels of society. This is to prevent misinformation, especially fake news in social networks. Training the media to handle this information properly is also important.

On the legislative/specification level, some necessary steps have been taken, such as the Guidelines on the Common Alert Protocol and the announcement published by the IFT, and in 2023, the technical preparation of the National Civil Protection Coordination (CNPC) to issue alert messages via mobile services.

Different countries have documented the effects of SWx events in recent decades. For example, in March 1989, the electrical grid of the Hydro-Quebec company in Canada reported the total failure of several electrical installations, which caused a nine-hour blackout and affected at least 6 million people, costing approximately $2 billion dollars. In October 2003, South Africa reported the permanent damage to 15 electrical power transformers caused by the geomagnetic storm. On May 10, 2024, a severe geomagnetic storm affected many countries. The northern lights were observed in Mexico, though this storm had a lower intensity than those mentioned above (González-Esparza *et al*. 2024).

It has been estimated that the global economic impact of an extreme SWx event would be approximately $2.4 to 3.4 billion dollars, losses comparable to an extreme financial crisis (Schulte in den Bäumen *et al*., 2014).

Given this panorama, it is clear that Mexico must take specific proactive measures to strengthen its response capacity against SWx, recognize its potential impact on technological systems safety, the economy, and people's well-being, and take Comprehensive Risk Management (CRM) actions.

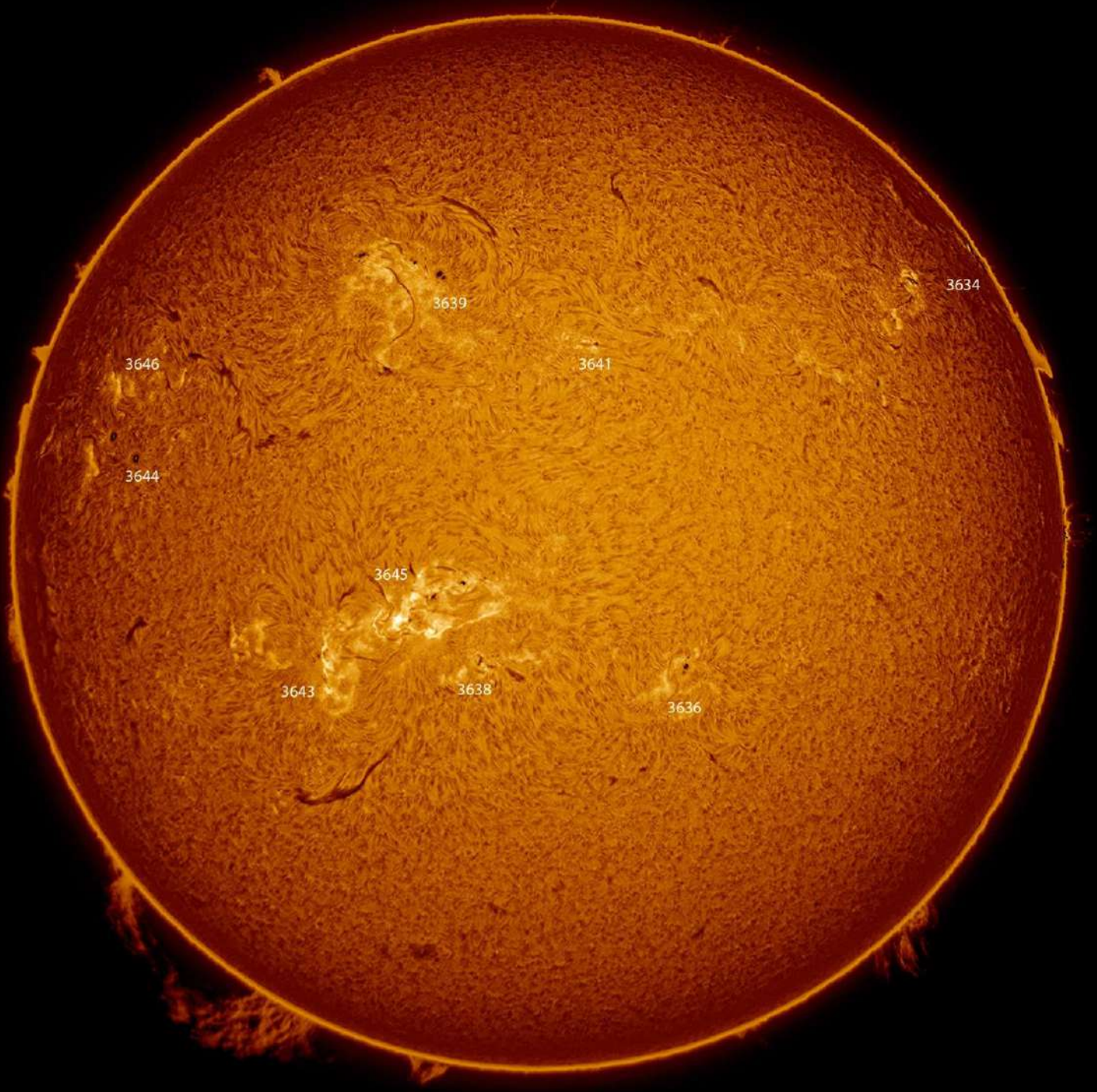
## Approach

CRM in Mexico is conceived as an extensive and multifaceted strategy designed to address risks from their origin, incorporating a permanent and collaborative approach that interconnects different levels of government and sectors of society. This approach focuses on sustainable development, a decrease in the number of structural causes of disasters, and the promotion of community resilience under unfavorable conditions. Within this framework, SWx management integrates itselfs harmoniously, aligning its strategic objectives with the key stages of CRM, from risk identification and analysis to post-disaster reconstruction. This approach is related to the strategic objectives proposed in this Guide.

The first strategic objective, the promotion of the development of scientific studies and an early warning system, focuses on the initial stage of identifying the risks associated with SWx events. The advances in our knowledge and alert capacity strengthen the bases for effective forecasting and prevention, which allows us to have a more informed and anticipated response to these events. This scientific and proactive approach is essential to understand the risk formations and minimize their potential impact on society.

The second strategic objective, related to the monitoring system, an early warning system, and promoting a culture of prevention and care, is part of the forecast, prevention, and preparation phases. Proper information on all institutional and social actors increases transparency and their participation in risk management and promotes prevention and preparedness practices throughout society. These stages are of major importance in setting up the necessary measures that allow people and critical sectors to respond effectively to the risk onset.

The third strategic objective is linked to the development of a prevention culture. This objective contemplates the distribution of information on SWx phenomena which contributes to the mitigation, assistance, recovery, and reconstruction phases. Raising awareness about these phenomena and their possible effects, strengthens the capacity of institutional and social actors to mitigate the risks through informed actions. Furthermore, this collective awareness and specific knowledge are central to the faster and more efficient recovery and reconstruction after a hazardous event, ensuring that the implemented public policies and strategies are effective and sustainable.




**Title.** Image of the solar chromosphere in H-alpha.
**Credits.** Photograph from the Spatial Geosciences Laboratory, National School of Higher Studies-Morelia, UNAM.

# STRATEGIC OBJECTIVES

## **STRATEGIC OBJECTIVE 1:** Promote the development of scientific studies to improve the current understanding of the matter and issuing of early warnings of the risks associated with Space Weather.

The regional study of SWx is a key issue for SWx risk management, that contributes to our understanding of the specific impacts, and improves the risk mitigation strategies, and the accuracy of early warnings that are more effective when adapted to local conditions. In this context, by conducting research and development of science focused on regional effects, the capacity of industrial and economic sectors and governments to anticipate, respond, and adapt to the unique challenges of SWx is being built.

Like any other region, Mexico is vulnerable to the adverse effects of SWx, making it necessary to carry out specific scientific studies on the issue. These studies seek to reveal the country's current and future exposure to SWx influence and to understand the interdependencies of our society with technologies susceptible to these events. This vulnerability manifests itself in the possible degradation or interruption of services essential for emergencies, health and well-being in general, underlining the importance of a proactive approach in the study of SWx. In this context, monitoring and diagnosing SWx conditions, generating early warnings, and developing guidelines for protecting both space and terrestrial systems are essential to mitigate impacts and safeguard critical infrastructure within our nation.

Internationally, the relevance of these efforts has been recognized and addressed by the Radiocommunications section of the International Telecommunication Union (ITU-R) in forums such as the 2019 World Radiocommunication Conference (WRC-19), which highlighted the importance of protection of the SWx sensors from interference with other radio communication services. The actions recommended by WRC-19 aimed to protect these sensors through appropriate regulations demonstrate a global consensus on the need to preserve and improve the SWx monitoring capabilities. Thus, the continuous work of the ITU-R 7C working subgroup prepared the ground for the 2023 World Radiocommunication Conference (WRC-23) to include the definition of Space Weather in the Radio Regulations. This recognizes the importance of using the electromagnetic spectrum by applications to monitor SWx phenomena that affect the services necessary for the economy, safety, and security of the administrations and people. This provides an example of the international collaborative effort to improve the understanding and management of SWx.

Mexico's active participation in these global efforts through the development and contribution of regional scientific studies on SWx proves its commitment to the safety and prosperity of the country and its role as a responsible actor in the international community. It is imperative to develop national infrastructures dedicated to monitoring and analyzing SWx, such as those implemented through LANCE. This approach seeks to guarantee Mexico's resilience in the face of SWx challenges and strengthen its capacity to contribute to national sovereignty in these hazards. In summary, the active stand in the studies and management of SWx is crucial to anticipate, mitigate, and respond

effectively to its possible impacts, thus ensuring the well-being and safety of Mexican society in the present and future.

Considering the above, within the framework of Strategic Objective 1, the following actions are suggested:

| Specific Actions | Request | Actors |
|---|---|---|
| Reveal the peculiarities of the regional SWx effects within the national territory to establish the parameter thresholds of severe and extreme events. | Maintain and develop networks of instruments that cover the national territory to measure different physical SWx variables and save historical records that cover at least two solar cycles of 11 years. | CONAHCYT, AEM, IFT, CFE, SICT, LANCE and Academic Institutions. |
| Reveal the peculiarities of the geomagnetic response of different regions of the country under the occurrence of SWx events. | Develop a network of magnetometers to record magnetic disturbances in real time at different sites within national territory. Data analysis by LANCE. | CONAHCYT, LANCE and Academic Institutions. |
| Reveal the peculiarities of the ionospheric response of different regions of the country under the occurrence of SWx events. | Develop the network of ionospheric stations for the diagnostics of the state of the ionosphere over national territory. Data analysis by LANCE. | CONAHCYT, LANCE, IFT, SICT, SENEAM and Academic Institutions. |
| Measure the flows of solar energetic particles that reach the national territory when solar storms occur. | Develop the network of cosmi rays detectors to record disturbances in real time at different sites within national territory. Data analysis by LANCE. | CONAHCYT, LANCE, SICT, SENEAM and Academic Institutions. |
| Reveal the occurrence of solar storms through radio burst measurements. | Develop the network of radio spectrograph detectors to record solar storms in real time from different sites within national territory. Data analysis by LANCE. | CONAHCYT, LANCE and Academic Institutions. |
| Reveal the geomagnetically induced currents in priority 400 KV transformers of the CFE in the event of geomagnetic storms. | Develop a network of geomagnetically induced current meters to register in real time disturbances in the national electrical system from different 400 KV priority transformers of the CFE. Data analysis by LANCE. | CONAHCYT, CFE, LANCE and Academic Institutions. |
| Reveal in real time disturbances in the interplanetary medium that can impact the Earth and cause SWx disturbances. | Operate, maintain and update the MEXART radio telescope to detect disturbances in the interplanetary medium using the Interplanetary Scintillation technique. Data analysis-by LANCE. | CONAHCYT, LANCE and Academic Institutions. |

| Specific Actions | Request | Actors |
|---|---|---|
| Develop hazardous and risk scenarios for severe and extreme SWx events and their impact in different regions of the country. | Analyze physical parameter variations in different regions of the country based on the data provided by networks of proper instruments. Financing to develop research. Financing for student scholarships. Hiring of researchers. | CONAHCYT, LANCE, AEM, CNPC, CENAPRED and Academic Institutions. |
| Develop SWx indicators that allow us to inform people efficiently about the status of SWx and the level of risk of a SWx event. | Implement a set of lights system or develop an equivalent product for different SWx areas of impact: The Sun, geomagnetic field, terrestrial ionosphere and solar energetic particles precipitations. | LANCE, SCiESMEX and CENAPRED and Academic Institutions. |

**Title.** Image of an aurora borealis.
**Credits.** Photograph by Cesar Cantú.

## **STRATEGIC OBJECTIVE 2.** Introduce the principles of monitoring and issuing of early warnings to institutional and social agents.

A severe or extreme SWx event not only represents a threat to technological systems and, consequently, society, but also to safety, economy and well-being in general. In the context of CRM, both institutional and social actors should understand how to use effectively and efficiently the information from monitoring and early warnings. The aim is to provide a timely response, thus mitigating the possibility of degradation in the operation of different technological systems and/or their significant damage.

Early warnings are a set of components that provide important information that helps authorities to act accordingly. An effective early warning system requires collaboration between the scientific sector and the cilvil protection authorities, where the sources of potential risks are revealed and the risk level is estimated. The SWx service is responsible for monitoring and issuing alerts based on scientific data and communicating and alerting the SINAPROC decision-makers. In Mexico, SCiESMEX/LANCE carries out SWx monitoring tasks, providing essential data and products to inform SINAPROC of the risk of significant events.

Technological systems essential to society, including those that support critical services, show notable vulnerability to extreme solar storms. Article 24 of the General Civil Protection Law designates the National Civil Protection Communication and Operation Center (CENACOM) as the operational axis for communication and coordination within the SINAPROC, focused on the preparation, action, and recovery phases. CENACOM integrates and manages the necessary resources for timely and adequate decision-making. Correspondingly, SCiESMEX/LANCE issues the SWx bulletins certified under the ISO 9001 Standard, ensuring reliable information delivery to SINAPROC under SWx conditions that can significantly affect our region.

Implementing and operating the Early Warning System (EWS) in the context of SWx amplifies the capacity for anticipation and response while strengthening national and international efforts to ensure resilience against these natural authorities. Therefore, the system implementation and understanding of how this system works among all the sectors involved are essential for safety and civil protection at all levels.

Considering the above, the following actions are suggested:

| Specific Actions | Request | Actors |
|---|---|---|
| Inform the National Civil Protection System on the occurrence of any event that can have significant effects over the national territory. | Operate and maintain the monitoring instruments and the warning system by Mexican Space Weather Service of the UNAM. | UNAM. |
| Work on the identification of the needs of sectors that operate the systems based on radio signals that are reflected from or pass through the ionosphere. Provide information to these sectors on the effects of SWx by issuing SWx bulletins. | Share information between the actors about the systems that currently operate and those that are planned to be put in operation in the short, medium and long term. | CNPC, CENAPRED, AEM, LANCE-UNAM, IFT, SICT and Academic Institutions. |
| Deliver workshops, exposition events and/or conferences targeted on decision makers from various different technological sectors vulnerable to SWx, during which the products and services addressing SWx risks and related topics are presented. | Management of the three levels of government for distribution and cooperation with potentially interested actors. | CNPC, CENAPRED, LANCE-UNAM and Academic Institutions. |

**Title**. Artistic image of the Sun.
**Credits.** Image by Catalina Armendáriz.

## **STRATEGIC OBJECTIVE 3.** Promote the development of the culture of prevention and attention regarding the risks associated with Space Weather events.

The relevance of this objetive lies in its potential to transform our understanding and response to complex SWx phenomena into particular steps and effective preventive measures that protect society and critical systems from potential hazards.

SWx, with its solar storms and geomagnetic events, represents an emerging risk that, despite its extraterrestrial origin, has tangible and potentially devastating impacts on Earth's technology, economies, and well-being in general. Faced with this, it is important to create a culture of prevention and attention within which the operators, institutions, and governments have the knowledge and tools to mitigate the risks. This culture is built on education and awareness, promoting a deep understanding of SWx phenomena, its mechanisms and effects, and the most effective adaptation and mitigation strategies.

Promoting the culture of prevention involves distributing information on the currently applied early warning and monitoring systems and how decision-makers can interpret the information and act accordingly. This includes implementing emergency protocols for critical infrastructure. The active participation and collaboration between different sector agents are essential to creating more resilient communities.

Notably, Strategic Objective 3 aligns with the vision of sustainable development, which seeks to prevent the adverse effects of SWx and ensure that society can adapt and prosper under these challenges. Ultimately, developing a culture of prevention and attention increases collective resilience, ensuring that we are better prepared to confront and overcome the risks of SWx, thereby protecting the legacy and future of our communities and nations.

During a severe or extreme SWx event affecting Mexico, some or all of the following effects can be expected: the failure or degradation of radio communications, especially in HF (3-30 MHz) and LF (30-300 kHz) ranges; communication problems with airplanes, ships and vehicles that use the HF and LF bands; problems in artificial satellites (orientation-navigation and tracking-tracking surface charge or radiation that affect memory devices and computers and solar panels; noise in imaging systems); the increased errors or failure in geopositioning and satellite navigation systems (GNSS); and disturbances in power transformers and voltage regulation equipment of the national electrical system.

Considering the above, the following recommendations are made:

| Specific Actions | Request | Actors |
|---|---|---|
| Establish the Scientific Advisory Committee on Space Weather in Mexico. | Management of the three levels of government for information distribution and cooperation between potentially interested actors. | CNPC, CENAPRED, AEM, LANCE and UNAM. |
| Promote a social communication strategy under SWx events that can have significant influence which may include tools such as press releases, social media content and media interviews. | Development of items and content that may be used in a timely manner in the media and avoid misinformation and people's agitation. | LANCE, AEM, UNAM, CENAPRED and CNPC. |
| Promote the creation of guides for the development of programs and plans that include forecasts of SWx events. | Management with the three levels of government for the inclusion of response protocols that consider SWx events. | CENAPRED, CNPC and LANCE. |
| Promote the creation of the specialized studies on the vulnerability of the national electrical system. | Perform the detailed vulnerability study that determines the necessary actions to prevent damage to the national electrical system due to the geomagnetically induced currents, thus avoiding the short- and long-term blackouts. This study will provide the essential information about the vulnerable substations and those that can be at greater risk of total disconnection during a solar storm. | CFE, CENACE, CNPC, CENAPRED, AEM, LANCE and UNAM. |
| Promote the implementation of the emerging preventive measures program in the National Electrical System. | The program will be aimed to seek the reliability and continuity of the electrical service to people and to the strategic sectors which includes actions applied to the primary equipment, generators, transmission and distribution lines in coordination with CENACE, CFE, public and private generators, the nuclear power facility *Laguna Verde*, as well as customers, to avoid damage to electrical infrastructure and extensive blackouts. | CFE, CENACE, CNPC, CENAPRED, AEM, LANCE y UNAM. |

| Specific Actions | Request | Actors |
|---|---|---|
| Perform a study to estimate the installation of protection devices at the strategic points of the electrical infrastructure. | Study the possibility of installing the protection devices such as geomagnetically induced current limiters at certain critical points of the electrical infrastructure, as well as applying the actions in the electrical network to reduce the effect of an extreme solar event. | CFE, IFT and CENACE. |
| Under a SWx event, follow the ICAO recommendations to protect the safety of passengers and air navigation crew. | Keep aeronautical technical/operational personnel informed and create plans to foresee contingencies. | SICT, AFAC and SENEAM. |
| Under a SWx event that affects radio communications, notify the users and operators to implement responsivity and mitigation measures. | Develop a warning system for users and operators of the potentially affected radio communications systems. | SICT, IFT, AEM, CENAPRED and CNPC. |
| Support institutions that request to develop an action plan. It is recommended that each user develop their own action plans as it depends on the type of the system and equipment in use (technical characteristics), mode of operation, etc. For example, satellite communication systems and HF systems require different actions. | Management with the three levels of government and support from Academic Institutions. | AEM, LANCE-UNAM, CNPC, IFT and Academic Institutions. |
| Inform and sensitize the population about the risks associated with the extreme SWx events. | Making information materials available to the public. | AEM, CNPC, CENAPRED, LANCE-UNAM, UNAM and state and municipal civil protection institutions. |
| Explaining the concepts of SWx phenomena to public to increase the general awareness about this type of phenomena and the preventive and preparedness actions that can be implemented. | Management with the three levels of government and support from Academic Institutions. | AEM, CNPC, CENAPRED, LANCE-UNAM, UNAM and state and municipal civil protection institutions. |

# EPILOGUE: Towards a resilient future in the Comprehensive Management of Disaster Risk associated with Space Weather events

The present guide addressed the issues of managing the risks associated with SWx events, which is an urgent need and a strategic opportunity to strengthen society in the face of already known and emerging challenges. SWx events have the potential to significantly impact the technological infrastructure and, as a consequence, the safety, the economy, and the social well-being, which urge us to apply a proactive and well-informed approach. The entities participating in this Guide preparation consider it crucial to look to the future with a renewed commitment to Comprehensive Risk Management of SWx hazards.

The future of SWx management will require unprecedented collaborative effort within the limits of the presented strategic objectives. The promotion of scientific studies and the improvement of early warning systems should continue to be the priorities to expand our understanding and capacity to respond to these phenomena. At the same time, it is essential that all sectors of society, from government to private, are actively involved in these efforts. Education and an effective information distribution are critical for the creation of a culture of prevention and preparedness that can mitigate the adverse effects of future events.

In this regard, the role of public policies is very important. As the officials charged with creating and managing disaster risk reduction policies, we must ensure that the implemented strategies are effective and adaptive. This implies integrating SWx management in the national development and civil protection plans and ensuring that public policies are committed to security, safety, education, and technological innovation.

This commitment to resilience must extend beyond the immediate responses to disasters, embracing the approach that promotes long-term adaptation and sustainability. This will require the ongoing evaluation of the applied methods and the readiness to adapt the practices as our understanding of SWx and its impacts evolves. In addition, international collaborations will continue to be necessary, given that SWx effects know no borders and its effective management, by its nature, is a global issue. At the same time, it is important to emphasize the need to develop scientific studies and SWx monitoring in the national territory since the harmful effects of SWx are different in different regions and countries.

As we look to the future, we anticipate and respond to the challenges presented by SWx and, built on these experiences, foster a more resilient and sustainable development. Through education, cooperation, and innovation, we can aspire to a future in which society survives the challenges of SWx and prospers, ensuring the legacy for the safety and well-being of future generations. In this endeavor, every action taken today is a step towards building a resilient and sustainable future.

# REFERENCES


Cannon, P., Angling, M., Barclay, L., Curry, C., Dyer, C., Edwards, R., ... & Underwood, C. (2013). Extreme space weather: impacts on engineered systems and infrastructure.

Caraballo, R., González-Esparza, J. A., Sergeeva, M., & Pacheco, C. R. (2020). First GIC estimates for the Mexican power grid. *Space Weather*, *18*(2), e2019SW002260.

Corona-Romero, P., González-Esparza, J. A., Villanueva-Hernandez, P., Andrade-Mascote, E., Castellanos-Velazco, C. I., Espinosa-Jimenez, A. R., & Sergeeva, M. A. (2024). The Geomagnetic Stations Network of Mexico (REGMEX): The initial steps towards a real-time monitoring of geomagnetic activity in Mexico. *Journal of Atmospheric and Solar-Terrestrial Physics*, *256*, 106204.

De la Luz, V., González-Esparza, J. A., Sergeeva, M. A., Corona-Romero, P., González, L. X., Mejía-Ambriz, J. C., ... & Monstein, C. (2018, October). First joint observations of space weather events over Mexico. In *Annales geophysicae* (Vol. 36, No. 5, pp. 1347-1360). Copernicus GmbH.

EXECUTIVE OFFICE OF THE PRESIDENT WASHINGTON DC. (2019). National Space Weather Strategy and Action Plan.

González-Esparza, J. A., (2022), *La tormenta solar perfecta,* Universidad Nacional Autónoma de México, ISBN 978-607-30-6560-3. (https://librosoa.unam.mx/handle/123456789/3607).

González-Esparza, J. A., De la Luz, V., Corona-Romero, P., Mejía-Ambriz, J. C., González, L. X., Sergeeva, M. A., ... & Aguilar-Rodriguez, E. (2017). Mexican space weather service (SCiESMEX). *Space Weather*, *15*(1), 3-11.

González-Esparza, J. A., Sanchez-Garcia, E., Sergeeva, M. A: *et al*. The Mother's Day geomagnetic storm on May 10, 2024: Aurora Observations and Low Latitude Space Weather Effects in Mexico. *ESS Open Archive* . August 19, 2024.

González-Esparza, J. A., Sergeeva, M. A., Corona-Romero, P., Mejía-Ambriz, J. C., González, L. X., De la Luz, V., ... & Romero-Hernández, E. (2018). Space weather events, hurricanes, and earthquakes in Mexico in September 2017. *Space Weather*, *16*(12), 2038-2051.

Hapgood, M., Angling, M. J., Attrill, G., Bisi, M., Cannon, P. S., Dyer, C., ... & Willis, M. (2021). Development of space weather reasonable worst-case scenarios for the UK national risk assessment.

ICAO. (2019). ICAO manual on space weather information in support of international air navigation (1st ed.). ICAO Doc 10100. ISBN 978-92-9258-662-1.

Koskinen, H., Tanskanen, E., Pirjola, R., Pulkkinen, A., Dyer, C., Rodgers, D., ... & Hilgers, A. (2001). Space weather effects catalogue. *ESA Space Weather Study (ESWS)*, 2, 11-21.

Hazard definition and classification review: Technical report, United Nations Office for Disaster Risk Reduction International Science Council (ISC). (2020). (https://www.undrr.org/publication/hazard-definition-and-classification-review-technical-report).

Hazard Information Profiles (HIPs), United Nations Office for Disaster Risk Reduction International Science Council (ISC) (2021) (https://www.undrr.org/publication/hazard-information-profiles-hips)

Mann, I. R., Di Pippo, S., Opgenoorth, H. J., Kuznetsova, M., & Kendall, D. J. (2018). International collaboration within the United Nations Committee on the Peaceful Uses of Outer Space: Framework for international space weather services (2018–2030). *Space Weather*, *16*(5), 428-433.

Report ITU-R RS.2456-1 (09/2023) Space weather sensor systems using radio spectrum. (https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-RS.2456-1-2023-PDF-E.pdf).

Schulte in den Bäumen, H., Moran, D., Lenzen, M., Cairns, I., & Steenge, A. (2014). How severe space weather can disrupt global supply chains. *Natural Hazards and Earth System Sciences*, *14*(10), 2749-2759.

Sergeeva, M. A. (2022). Space Weather General Concepts. In *Space Weather Impact on GNSS Performance* (pp. 89-150). Cham: Springer International Publishing.

Sergeeva, M. A., Maltseva, O. A., González-Esparza, J. A., Mejía-Ambriz, J. C., De la Luz, V., Corona-Romero, P., González, L. X., Gatica-Acevedo, V. J., Romero-Hernandez, E., Rodriguez-Martinez, M. and Aguilar-Rodriguez, E. (2018). "TEC behavior over the Mexican region", *Annals of Geophysics*, 61(1), p. GM104. doi: 10.4401/ag-7465.

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