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Review on space weather in Latin America. 3. Development of space weather forecasting centers

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Abstract

The present work is the third of a three-part review of space weather in Latin America, specifically observing its evolution in three countries (Argentina, Brazil and Mexico). This work presents the decision process for the spinning off of space weather prediction centers from space science groups with our interpretation of the reasons/opportunities that lead to this. Lastly, the constraints for the progress in space weather monitoring, research, and forecast are listed with recommendations to overcome them, which we believe will lead to the access of key variables for the monitoring and forecasting space weather, which will allow these centers to better monitor space weather and issue warnings, watches and alerts.

Keywords: Space science; Space weather; Space physics; Latin America

1. Introduction

Grounded in international initiatives established to improve space science research and to develop space weather forecast centers around the world, a few research centers in Latin American countries now have the conditions to step forward to undertake this challenge. They are making use of scientific knowledge about the solar-terrestrial environment accumulated from decades of research and are using it not only for the monitoring of space weather, but also to forecast and to provide watches and issue warnings and alerts to the public.

The motivation for the studying and monitoring of space weather, besides scientific advances made by curiosity, is also justified in terms of its effect on technological assets. In addition to solar wind variability, there has been a marked increase in changes to UV and X-ray radiation when solar bursts occur. These increases may change the behavior of the neutral atmosphere affecting the operation of satellites orbiting the Earth as well as the accuracy of satellite-based positioning received on the Earth's surface. Upon the arrival of solar ejecta, and assuming its geoeffectiveness, space weather conditions in the magnetosphere may change significantly, adversely affecting the electric power industry by producing Ground Induced Currents (GIC). Even during solar quiet periods, the ionospheric plasma bubbles triggered by Gravity Waves (GW) are responsible for introducing scintillation to the Global Navigation Satellite Systems (GNSS) signal, which reduces its

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detectably leading to (occasionally) the loss of the ability to lock onto a target.

Some economists believe that there is potential for significantly larger losses due to the adverse impact of space weather considering the current technological assets of modern society, and they estimate that it could range from 200 to 400 million dollars/year (Horne, 2003; NRC, 2007). Besides this general estimate, the space weather-related losses to satellite companies would range from thousands of dollars for temporary data outages up to hundreds of millions to replace a satellite (depending on the mission).

Conversely, Teisberg and Weiher (2000) stated that timely space weather warnings, can save millions of dollars. They recalled a geomagnetic storm that occurred in March 1989 led to a failure in the Hydro-Quebec electric power system and, as a consequence, 6 million people remained without electricity for 9 h. They use this fact to estimate that timely warnings of geomagnetic storms to the electric power industry would save approximately 150 million dollars/year. They also stated that avoiding a large-scale outage would save lives (e.g. surgeries), and would provide monetary savings of over 20 billion dollars. Rodgers et al. (2000) also support the idea that space weather warnings to the GNSS industry could avoid adverse effects on the systems. According to them, a 1% gain in the continuity and availability of the Global Positioning System (GPS) would be worth 180 million dollars/year.

As a natural response to these concerns, new international bodies are being created to congregate emerging Space Weather Regional Warning Centers (RWC) like the Asia Oceania Space Weather Alliance (AOSWA) established in 2010 to encourage cooperation and the sharing of information among institutes in the Asia-Oceania region concerned with and interested in space weather, and the International Space Environment Service (ISES) that has been the primary organization engaged in the international coordination of space weather services since 1962.[1]

In the following sections, we start from defining space weather to describing our view of the process leading to the development of the Latin American forecast centers, and close with some remarks on open questions and the perspectives on scientific and operational development regarding space weather.

2. The definition of space weather

At this point it important to mention that there is no full agreement on the exact definition of space weather among all the members of the international communities dealing with space weather. Hence, we list definitions of space weather according to several organizations (in alphabetical order) to exemplify the way that each community deals with the definition based on its culture and aims:

1. American Meteorological Society (AMS): "Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space-borne and ground-based technological systems, as well as endanger life or health".[2]
2. Asia Oceania Space Weather Alliance (AOSWA): "Space weather is the electromagnetic condition in the near-space around the Earth and it affects telecommunications, broadcast, satellite positioning and many of other social infrastructures".[3]
3. European Space Agency (ESA): "Space weather refers to the environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of space-borne and ground-based systems and services or endanger property or human health. Space weather deals with phenomena involving ambient plasma, magnetic fields, radiation, particle flows in space and how these phenomena may influence man made systems. In addition to the Sun, non-solar sources such as galactic cosmic rays can be considered as space weather since they alter space environment conditions near the Earth".[4]
4. U.S. Office of Science and Technology Policy of The White House: "Space weather refers to the dynamic conditions of the space environment that arise from interactions with emissions from the sun, including solar flares, solar energetic particles, and coronal mass ejections" (Wackler, 2015).
5. U.S. National Space Weather Program: "The term 'space weather' refers to the variable conditions on the Sun, throughout space, and in the Earth's magnetic field and upper atmosphere that can influence the performance of space born- and ground-based technological systems and endanger human life or health. Adverse conditions in the space environment can disrupt satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses and impacts on our security. As our society becomes more technologically advanced, our vulnerability to space weather significantly increases" (Williamson et al., 2010).
6. World Meteorological Organization (WMO): "Space weather encompasses the conditions and processes occurring in space, including on the sun, in the magnetosphere, ionosphere and thermosphere, which have the potential to affect the near-Earth environment".[5]

[1] Prior to 1996, ISES was called the International URSIgram and World Days Service (IUWDS).

[2] Available online at http://www.ametsoc.org/policy/2008spaceweather_amsstatement.html.

[3] Available online at http://aoswa.nict.go.jp/.

[4] Available online at http://swe.ssa.esa.int/web/guest/what-is-space-weather.

[5] Available online at http://www.wmo.int/pages/prog/sat/spaceweather-intro_en.php.

Over all, each of these definitions tries to encompass the Solar-Terrestrial environment, including the Sun, the Interplanetary Medium, the Magnetosphere in all its scope, and the Earth's Atmosphere. Some of them focused on the phenomenology observed in this environment (e.g. solar flares, solar energetic particles, coronal mass ejection, ambient plasma, magnetic fields) while others pay closer attention to the effect of such phenomena on the Earth's environment or on the technological objects/systems exposed to these phenomena (e.g. space-borne and ground-based systems, and services like telecommunications, broadcast, and satellite positioning). The definition provided by ESA is the only one to consider galactic cosmic rays as space weather. Ultimately, the WMO definition is, to us, the most generic physical-based description, which includes not only the possibility of encompassing galactic cosmic rays, as recalled by ESA, but also supernova explosions (Heger et al., 2003). Therefore, for the present work, we consider the following definition:

Space weather encompasses the conditions and processes occurring in space, which have the potential to affect the near-Earth environment and/or human beings or the current technological assets.

The study of space weather is hence considered as a specialization of space science research related to the behavior of the Sun, the Interplanetary Medium, the Magnetosphere or Geomagnetic Field (in all its scope), and the Earth's Atmosphere (both neutral and ionized). It also includes studying the nature of associated phenomenology from above (e.g. solar explosions, ejections, and solar wind variabilities and its transients) and from below (e.g. GWs and plasma bubbles).

3. Development of the Forecast Centers in Latin America

From our experience and research, the keystone for taking a step forward to developing forecasting centers in Latin America seems to require being part of the international initiatives, sharing and taking advantage of each other's experience. For example, the three Latin American countries (Argentina, Brazil and Mexico) taken as examples for the present work provided space weather specialists to be part of a team named the Interprogramme Coordination Team on Space Weather (ICTSW) and established by the WMO, whose aims are to discuss the standardization and enhancement of space weather data, the harmonization of end-products and services, the integration of space weather observations into operational systems, and to encourage a dialogue between the research and operational space weather communities. Consequently, these space weather specialists may certainly have taken advantage of the experience acquired from WMO and the global coordination aspects of the weather forecasting operational centers.

In addition, the Latin American Research Center/Universities (institutions) are the drivers of the evolution from space weather research to space weather operations. We are also confident to state that none of the Latin American government agencies have taken note of the importance of space weather for the society. In this scenario, ISES is playing an import role in bringing the Latin American Research Centers/Universities to the level that they can start their own operational space weather forecasting centers. By taking advantage of the experience accumulated from RWC of other countries (Williamson et al., 2013; Freng et al., 2013), the Latin American institutions are organizing their activities more efficiently, saving time and resources.

After interacting within ISES representatives, the first RWC was created in 2007 in Latin America at National Institute for Space Research (INPE) under support of the Ministry of Science, Technology and Innovation (MCTI) of Brazil, and was called the Brazilian Study and Monitoring of Space Weather (Embrace/INPE) Program, RWC-Brazil. The mission of the Embrace/INPE program is to monitor the Solar-Terrestrial environment, the magnetosphere, the upper atmosphere and the Ground Induced Currents to prevent effects on technological and economic activities. It monitors the physical parameters of the Sun–Earth environment, such as Active Regions (AR) in the Sun and solar radiation by using radio telescope, Coronal Mass Ejection (CME) information by satellite and ground-based cosmic ray monitoring, ionospheric disturbance by ionospheric sounders and using data collected by four GPS receiver networks, and geomagnetic activity by its own magnetometer network.

The underlying motive for the creation of the Embrace/INPE Program was based on the scientific knowledge collected in 2007, i.e. there are three particular phenomena from the space climate perspective in the South American continent. One is the Equatorial Ionospheric Anomaly (EIA) along the longitudinally extended zone from 35° to 80°W, almost 5000 km of extension. The second is strong equatorial ionosphere scintillation phenomenon caused by ionospheric plasma bubble activities. The ionospheric scintillation affects radio wave propagation, such as satellite to ground communication and GNSS signal applications. The third point is the South American Magnetic Anomaly (SAMA), where the magnetic field's main field is almost half as strong as other regions. Consequently, a large amount of high energy particles penetrate into the upper atmosphere and ionosphere. The information of geomagnetic activity and high-energy particle flux is crucial information for satellite operation.

The original purpose of the Embrace/INPE Program was to proceed with data collection and maintenance of space weather observation, modeling processes of the Sun–Earth through a global and regional investigation of the phenomena provide information in real time and make space weather forecasting possible. This observation and modeling also provides diagnostics of the effects of space weather on different technology systems through the collection of satellite data and surface and computational modeling. Since it receives a substantial budget to achieve its purposes, the program naturally became an attractor of a research project that could easily transit from Research to Operations (R2O). Therefore, the Embrace/INPE Program was assigned with the task to collect a considerable portion of scientific data related to space weather in Brazil, including its permanent storage, release, and usage accountability.

Additionally, real-time data processing of most of the data collected from the networks and instruments mentioned by Denardini et al. (2016) is automatically performed at the data processing center of the RWCs. Therefore, besides providing the public with useful information regarding space weather, RWCs provides the scientific community with easily accessible information to support ongoing scientific research. An example is the Embrace/INPE map of Total Electron Content (TEC), which was derived from the four GNSS receiver networks available in Latin America. It has been used to inform the public about GPS estimation errors as well as to supply data for near real-time assimilations in the Sheffield University Plasmasphere–Ionosphere Model (SUPIM) model. Also, it seems fair to state that such routine data processing may lead to a natural increase in the scientific publications and, in turn, a greater insertion of the Latin American scientific community into the global community, as we can see by the growing number of publications made by Brazilian PhD researchers associated with the Embrace/INPE Program in the scientific publications database (e.g., Moro et al., 2012a,b; Resende et al., 2013; Resende, 2014; Nogueira et al., 2013a,b, 2015). Finally, another contribution of the RWCs comes from taking the administrative burden of purchasing, maintaining and sustaining the instrumental network out of the duty of scientists, which allows them more time for real research. Thus, we see clear contributions from the advent of RWCs for Space Weather Forecast and Monitoring to space science and space weather researchers.

To support this claim, several internal and external conditions have recently been created which promoted the establishment of Mexican Space Weather Service (SCiESMEX), the current RWC-Mexico. This service was founded in 2014, as an initiative of the Institute of Geophysics (IGF) of the National Autonomous University of Mexico (UNAM), in the new heliophysics and space weather group in Morelia. The antecedents for this project include: (1) after a couple of attempts in the past, the Mexican Space Agency was finally created in 2010; (2) recent modifications (6/2014) to the Mexican General Civil Protection Law, now explicitly include space hazards and extreme space weather phenomena; (3) there was also the effort of the federal government to decentralize and expand the development of science and higher education across the Mexican country, raising new opportunities to develop research and plans of action outside of Mexico City; (4) in 2014, a new program of the National Council of Science and Technology (CONACyT) promoted the renewal of the national scientific body, creating new positions in emerging research areas; one of the projects supported by this initiative was the creation of the SCiESMEX and four young researchers (Victor de la Luz, Julio Mejia-Ambriz, Pedro Corona-Romero and Luis Xavier Gonzalez) were contracted to operate the service.

In addition, the IGF/UNAM had a consolidated group in space physics and a ground-based instrumental network, in addition to its expertise in managing critical services such as the National Seismological Service (SSN). These conditions combined with the initiative of the heliospheric and space weather group in Morelia made it clear that, for the situation in Mexico, the space weather service should be led and operated by IGF/UNAM. Another aspect that helped support the foundation of SCiESMEX was the global efforts and recommendations by the United Nations Office for Outer Space Affairs (UNOOSA) and Committee on Space Research (COSPAR), among others, to raise awareness and participate in international space weather collaborations. The SCiESMEX operation center is located in Morelia, Michoacán, at the UNAM campus. This service became a Regional Warning Center of ISES in May 2014. SCiESMEX also acts as the Mexican representative at WMO/ICTSW and participates in the space weather expert group at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOUPUS). The first objectives of SCiESMEX are: (1) to unify and combine the data of the UNAM network of ground-based instruments studying different aspects of the solar-terrestrial relations; (2) to incorporate their instruments with international networks, sharing data in near real time; (3) to participate in international space weather organizations, e.g. ISES and WMO/ICTSW; (4) to issue alerts in social networks to advise to the general public, governmental, private and military agencies of possible effects on the Earth's environment due to solar activity; (5) to perform space weather observations and do research in space physics within the Mexican territory; and (7) to develop outreach and educational activities. The SCiESMEX ground-based observational network includes: the Mexican Array Radiotelescope (MEXART) observatory, an Interplanetary Scintillation Radiotelescope; Geomagnetic Observatory associated to the International Real-time Magnetic Observatory Network (Intermagnet); Cosmic Rays Observatory (Mexico City); Global Muon Detector Network (GMDN at Sierra Negra); access to data of GPS networks in the Mexican territory; Schumann resonance station (at MEXART site); and a Compact Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (CALISTO) antenna (at the MEXART site).

Argentina is starting to take its first steps in the direction of creating its own RWC, but at the moment, it does not have a program to meet this demand. In 2014 a strong link between University of Buenos Aires (UBA) and Argentine National Weather Service (SMN) was made. They launched a program of different courses on space weather. For instance, the first course on space weather forecasting was taught in Argentina in 2014, and was coordinated by the Buenos Aires Regional Center of Weather Formation for Latin America (Centro Regional de Formación Meteorológica Buenos Aires). This center belongs to the WMO, and its management is in charge of SMN and the Department of Atmospheric Sciences and the Oceans (DCAO).

In addition to engage experienced space scientist and training young scientist in the space weather field, Argentina is starting to organize and improve the space weather related data collected in the country and abroad. New data from the Van Allen Probes mission of National Aeronautics and Space Administration (NASA) from the United States of America are being directly downloaded at the Space Center Teófilo Tabanera of the Argentine Space Agency (CONAE) since 2015, allowing an independent monitoring for radiation and geomagnetic field conditions in space. Also, several academic institutions in Argentina (e.g. UBA, National University of Tucumán, Argentine Antarctic Institute, and Bariloche Atomic Center) are starting to provide online real-time data from different instruments associated with space weather. However, at the moment, they provide data as isolated observatories.

Since 2014, Argentina has started participating in the recently created Space Weather panel of COSPAR. As of 2015, the Argentine space science community has also been participating with a representative in the WMO/ICTSW. Also, the first service of space weather forecasting was created following the visit of the WMO representatives to Argentina, who aimed to stimulate and support the local development of space weather activities. It is currently hosted by DCAO and comes from collaboration between UBA and SMN. Recently, in November 2015, the risk commission of the Ministry of Science of Argentina decided to include extreme space weather events as risky for communication systems, in the frame of threats of natural origin.

The next steps for Argentina include getting stronger support from government agencies in order to coordinate the producing of space weather data at Argentine centers, and to facilitate efficient on-line data sharing. Other important actions to be taken in the future are coordinating institutions that have different types of knowledge, developing operative research activities, and attaining new local space weather products, taking into account the demand of local space weather information.

As mentioned early, these aims will need strong support from governmental agencies to be realized. They require not only giving economic resources, but also helping with inter-institutional coordination, because there is a huge number of different institutions in Argentina that depend on different ministers or agencies, which have the capacities to contribute to the formation of a space weather program and a RWC.

However, despite being promising there is always a cost for every new program. In this case, the transit from R2O is a process that may impose various challenges to scientists. A lot of effort may be required to make the change from running models on single computers to running them in a high performance environment where it must operate for 24 h 7 days a week. There will certainly also be some activities that will demand lot of coordination and effort from several groups with (usually) different cultural backgrounds. To exemplify the above statements, the SUPIM Model started the transition from R2O under Embrace/INPE auspices. In a multi-departmental collaboration involving the Laboratory for Computing and Applied Mathematics and the Aeronomy Division, SUPIM had to undergo a process of parallelization of the code to run in groups (clusters) of computers to forecast daily maps of the quiet day TEC of geographic coordinates over the Latin America (Petry, 2010).

In addition to the R2O transition, RWCs raise a new paradigm to be incorporated into the scientific problem regarding space weather. Not only the scientific challenges have to be addressed now, but also the answer provided by the research has to match with the user's criteria (or needs). In general, the scientific community basically sees its users as the readers of the papers or the general public, who will benefit from the advance of science. Despite being correct in a sense, the RWCs have to broaden this concept to include also the users of their "product". Therefore, the monitoring and forecasting results provided by the RWCs now have to fulfill the expectations of the specific sectors of society that will directly benefit from them. Additionally, RWCs also have to provide information in sufficient time to be useful for those specific sectors of society. Otherwise, the research could be carried out as it usually is, i.e. as broad as the scientific theme and not with rigid timing constraints.

A good example of how the needs of the users can impact the orientation of the research and the timing is provided by the modeler community. When carrying curiosity-driven research, the research community typically prefers first-principles models. This may lead to the false premise that they are doing the right kind of research to meet user needs. However, statistics from the Space Weather Prediction Center (SWPC) in the United States of America revealed that the empirical models do better than they are expected to do, in both time of processing and quality of the result (Thomas J. Bogdam, Private Communication). Essentially, empirical models are powerful tools for operators, but sometimes are neglected by the scientific community. So, if the RWCs want better operational performance, we have to set aside some research funding for models that are user-oriented, not necessarily understanding-oriented. This will involve the carving out of existing programs or creating new ones.

In the end, even considering only the cost without recalling the benefits of this new activity, we are convinced that accurate space weather prediction could save the public hundreds of millions of dollars a year. As the modern world becomes more dependent on technologies that are vulnerable to changes in the near-Earth environment, the need for accurate forecasting only increases. Forecasters continually monitor the space environment using both space- and ground-based assets and issue alerts, whatchs and warnings of a likely impact on the Earth. These instruments also provide the space weather community with a long-term baseline, on which to base, test, and ultimately improve global prediction models.

Current space weather predictions are focused primarily on the following five areas: (1) solar flares and eruptions impacting communications, radar, and GPS receivers; (2) radiation storms affecting airlines companies, astronauts, satellites, and communications; (3) disturbances in Earth's magnetic field, impacting electrical power grids, satellites, and airlines; (4) atmospheric heating from increased short wavelength radiation, which shortens the lifetime of low-Earth-orbiting satellites; and (5) ionospheric storms, which degrade navigation systems, GPS-dependent technologies, and high-frequency and satellite communications.

4. Remarks and perspectives for development

Several speakers at meteorological conferences where space weather forecasting is being discussed say (with the endorsement of the American Meteorological Society) that currently "...our capability to predict space weather events is comparable to Earth weather forecasting of about a half-century ago. Many space weather events are forecasted, but with minimal lead time because of a lack of real-time data and limited model capabilities. Considering the vast volume of space involved, the environment is highly under-sampled. Investments by the United States of America and the global community into space weather-related research and technologies are rapidly advancing the state of knowledge and show great promise for producing improved forecasting capabilities." Therefore, we would like to mention that by following the course of developing space weather capabilities, we have a historic opportunity to begin real and significant scientific collaboration in the Latin American community of space science and advance our society to a safer position regarding space weather effects.

Indeed, it seems that some steps forward are being taken by the research community in Latin America to fulfill or advance the knowledge regarding space weather, like building single instruments or developing sensor networks. Others may need access to space to guarantee that Latin American will truly contribute to answering the open issues and challenges. These research communities may require a space platform such as a space weather satellite mission. The ideal solution would be conceiving the mission, developing, building, and integrating the payload and platform, and successfully launching the satellite within the Latin American countries.

Despite all of the progress being made, new challenges in space weather effect forecasting are still unacknowledged. Most scientific research groups are not aware of these challenges and some of the RWCs around the world are just ignoring them. For example, the study currently being carried out to develop an ionospheric scale is under discussion (Jakowski et al., 2012; Schlüter et al., 2013; Sanz et al., 2014). This study aims to translate the scientific information obtained from TEC maps into a simple disturbances scale to be released to the general public. In this study, there certainly is room for contribution from the Latin American community. These countries hold research groups in the field and there are global singularities observed in the TEC map regarding the latitudinal, longitudinal and seasonal distributions of the ionospheric phenomena (e.g. the occurrence of plasma bubbles, the intensity of the EIA, and the scintillation weaknesses compared to the African sector), which justify experiments being carried out in Latin America. They could come from the identification of temporal variabilities of such phenomena or from the mapping of these variabilities in the ionospheric spaces, and take advantage of an excellent opportunity to keep our research on the frontier of space weather knowledge.

Politically, one of the biggest challenges of space science in Latin America is the lack of a concrete policy, a development medium and a well-defined long-term plan (including adequate legislation for developing, purchasing, transporting, importing–exporting, scientific equipment and material) to promote the financial support and renewal of qualified human resources to carry out national and international goals in this field. Ideally, this activity should be carried out by a coordinating body, preferably under the governmental agencies with institutional support. As a matter of physical infrastructure, this body could be housed initially in one of the institutes of the Latin American countries provided that the institution could offer adequate infrastructure and local support. A short-term action would be the sending of documents by existing organized associations like the Latin American Space Geophysics Association (ALAGE), the Argentine Association of Astronomy (AAA), the Argentine Geophysical and Surveyors Society (AAGG), the Brazilian Astronomical Society (SAB), and the Brazilian Association for Space Geophysics and Aeronomy (SBGEA) shedding light on this matter and bringing the discussion to the attention of the proper authorities.

Besides the political engagement of the existing organized societies, it is also recommended that these Latin American societies make an effort to establish ties between the local scientists and Latin Americans living abroad (especially those with permanent resident visas) so as to promote the local dissemination of knowledge collected abroad in order to help complete the cycle in Latin America. The first step toward realizing this suggestion would be an ordinary register of the Latin American scientists including their affiliation (and contact information) and ongoing projects. Additional steps would involve active measures to promote the exchange of knowledge among them.

The development of space weather research in Latin America must face the challenges listed here as well as others that we may not have addressed. Although we discussed major challenges in the advancement of space weather research, development may also come from more modest steps like: (1) coordinating the monitoring of space weather throughout the continent; (2) sharing data (considering commissioning time) with other countries and scientists; (3) cooperating by disseminating knowledge among the Latin American countries to achieve common goals; and (4) establishing scientific campaigns to address open issues.

5. Summary and conclusions

We emphasized the fact that Latin America is promoting the development of space weather forecasting centers. Through this development, we commented on the advantages of further scientific research. We also discussed the new paradigm being incorporated into the scientific problem regarding space weather data and forecasting being more widely used, i.e. matching with the user's criteria (or needs). We provided a short list of potential users of space weather products in the five following areas: (1) solar flares and eruptions; (2) radiation storms; (3) disturbances in Earth's magnetic field; (4) atmospheric heating from increased short wavelength radiation; and (5) ionospheric storms. Finally, we stated the most highly recommended actions to advance both space weather knowledge and operation capabilities.

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Appendix A
Abbreviations for organizations (institutions, associations, committees, groups, observatories, services and related terminology).

AAA	Argentine Association of Astronomy, from the Spanish Asociación Argentina de Astronomía
AAGG	Argentine Geophysical and Surveyors Society, from the Spanish Asociación Argentina de Geofísicos y Geodestas
ALAGE	Latin American Space Geophysics Association, from the Spanish Asociación Latino Americana de Geofísica Espacial
AMS	American Meteorological Society
AOSWA	Asia Oceania Space Weather Alliance
CONACyT	National Council of Science and Technology, from the Spanish Consejo Nacional de Ciencia y Tecnología
CONAE	National Commission on Space Research, from the Spanish Comisión Nacional de Actividades Espaciales
COSPAR	Committee on Space Research
DCAO	Department of Atmospheric Sciences and the Oceans, from the Spanish Departamento de Ciencias de la Atmósfera y los Océanos
Embrace	Brazilian Study and Monitoring of Space Weather, from the Portuguese Estudo e Monitoramento Brasileiro de Clima Espacial
ESA	European Space Agency
ICTSW	Interprogramme Coordination Team on Space Weather
IGF/UNAM	Institute of Geophysics at UNAM, from the Spanish Instituto de Geofísica de la UNAM
INPE	National Institute for Space Research, from the Portuguese Instituto Nacional de Pesquisas Espaciais
ISES	International Space Environment Service
IUWDS	International URSIgram and World Days Service
MCTI	Ministry of Science Technology and Innovations, from the Portuguese Ministério de Ciência Tecnologia e Inovação
NASA	National Aeronautics and Space Administration
RWC(s)	Regional Warning Center(s)
SAB	Brazilian Astronomical Society, from the Portuguese Sociedade Astronômica Brasileira
SBGEA	Brazilian Association for Space Geophysics and Aeronomy, from the Portuguese Associação Brasileira de Geofísica Espacial e Aeronomia
SCiESMEX	Mexican Space Weather Service, from the Spanish Servicio de Clima Espacial, México
SMN	National Weather Service, from the Spanish Servicio Meteorológico Nacional
SSN	National Seismological Service, from the Spanish Servicio Sismológico Nacional
SWPC	Space Weather Prediction Center
UBA	University of Buenos Aires, from the Spanish Universidad de Buenos Aires
UNAM	National Autonomous University of Mexico, from the Spanish Universidad Nacional Autónoma de México
UNCOUPUS	United Nations Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office for Outer Space Affairs
WMO	World Meteorological Organization

Appendix B
Abbreviations for assets (networks, systems, instruments, devices, models and related terminology).

CALISTO	Compact Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory
GMDN	Global Muon Detector Network
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
Intermagnet	International Real-time Magnetic Observatory Network
MEXART	Mexican Array Radiotelescope
SUPIM	Sheffield University Plasmasphere–Ionosphere Model

Appendix C
Abbreviations for physical and technological definitions (phenomena, techniques, procedures and related terminology).

AR(s)	Active Region(s)
CME(s)	Coronal Mass Ejection(s)
EIA	Equatorial Ionospheric Anomaly
GIC(s)	Ground Induced Current(s)
GW(s)	Gravity Wave(s)
R2O	Research to Operations
SAMA	South American Magnetic Anomaly
TEC	Total Electron Content

Appendix A

See Appendix A–C

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