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Review on space weather in Latin America. 1. The beginning from space science research

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Abstract

The present work is the first of a three-part review on space weather in Latin America. It comprises the evolution of several Latin American institutions investing in space science since the 1960s, focusing on the solar–terrestrial interactions, which today is commonly called space weather. Despite recognizing advances in space research in all of Latin America, this review is restricted to the development observed in three countries in particular (Argentina, Brazil and Mexico), due to the fact that these countries have recently developed operational centers for monitoring space weather. The review starts with a brief summary of the first groups to start working with space science in Latin America. This first part of the review closes with the current status and the research interests of these groups, which are described in relation to the most significant works and challenges of the next decade in order to aid in the solving of space weather open issues.

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

1. Introduction

In recent years, several international efforts have been initiated to improve space weather research and to develop space weather forecasting centers around the world. In 2012, the Committee on Space Research (COSPAR), an interdisciplinary scientific body concerned with the international progress of scientific investigations carried out using space vehicles, established a group called Space Weather Roadmap, which brought together specialists to discuss space weather from the scientific point of view and provide society with recommended actions. This committee, dedicated to addressing space weather issues and their relation to the technological assets of the modern society, was formed with a large number of space scientist specialists in various fields including solar astrophysics, magnetospheres and magnetic reconnection, geomagnetism, ionosphere, as well as other areas of the solar–terrestrial environment, which indicates that its current space weather monitoring facilities are grounded in space science research.

International space science research has discovered an alternative way to monitor space weather while centers are currently being built to prevent space weather from adversely effecting society, and the Latin American

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research community is part of it. In Latin America, in conjunction with the early international initiatives, the Latin American Space Geophysics Association (ALAGE) was created in 1993 during the third Latin American Space Geophysics Conference. One of its original objectives was to promote the scientific advancement in space geophysics. Recently, ALAGE is endeavoring to extend its aims to include collaboration in space weather research and services.

Therefore, in the present work we review the trajectory of space research in Latin America from near its beginnings (with some of the most significant scientific contributions). We have included highlighted research, which we believe helped prepare some groups to develop space weather operational forecasting centers. In the next section we describe various elements that enabled the international space science research community to provide an alternative shield from adverse space weather effects on society, in three Latin American countries (Argentina, Brazil and Mexico).

2. The beginning of space research in Latin America

Several research groups (or institutions) dedicated to space science have been created in Latin America in the last six decades. In the last ten years, some of these groups have been focusing on space weather research and monitoring. The early 1960s were a very profitable period for space research in Latin America. The Center of Radio Astronomy and Astrophysics Mackenzie (CRAAM) was founded in 1960, and the National Institute for Space Research (INPE) in 1961, both in Brazil. The Department of Outer Space Sciences at the Institute of Geophysics of the National Autonomous University of Mexico (IGF/UNAM) and the National Commission for Outer Space (CONEE) were founded in 1962, in Mexico. The Institute of Astronomy and Space Physics (IAFE) in 1969, in Argentina. After consolidation of the first scientific results of the space race in the late 1980s and early 1990s (Gall, 1987), Latin America created the National Commission on Space Research in Argentina (CONAE) in 1991, the University Program of Space Research and Development in Mexico (PUIDE) in 1992 and the Brazilian Space Agency (AEB) in 1994. Recently, new generations of this category of institutions such as the Brazilian Study and Monitoring of Space Weather (Embrace/INPE) Program in 2007, Mexican Space Agency (AEM) in 2010, and Mexican Space Weather Service (SCiESMEX) in 2014 are being created with a more specific purpose.

In Brazil, like in most of the Latin American countries, space science started earlier than the space race, e.g., the studies of Cesare Mansueto Giulio Lattes (also known as César Lattes, 1924–2005), a Brazilian physicist who was awarded the 1950 Nobel Prize for the co-discovery of the subatomic particle Píon. However, the institutional space science research started in the early 1960s. CRAAM was founded in 1960 as the Group for Radio Astronomy Mackenzie, originally called GRAM at the Faculty of Philosophy, Sciences and Letters at Mackenzie University, incorporating the experimental activities of a group of physics, engineering, and technical students, as well as the enthusiastic members of the Amateur Astronomer's Association in São Paulo. It contributed pioneering research in the areas of radio-sciences in Brazil, including radio astronomy, solar physics, solar–terrestrial relations, ionosphere physics, astrophysics, radio-scientific instrumentation and space sciences.

In the same period of the early 1960s, the Brazilian government created the National Commission Organization Group of Space Activities (GOCNAE). This group worked in the areas of astronomy, optical tracking of satellite and satellite communications. It was designed to perform space science studies in Brazil on August 3, 1961, which eventually led to what would be the embryo of the INPE, which was installed in São José dos Campos (SP). The initial research was based on the reception of beacon satellite signals from low earth orbiting satellites to measure the total electronic content of the ionosphere over Brazil. This was followed by the monitoring of the cosmic noise intensity by Riometers for the study of the lower ionosphere and the recording of the Earth's magnetic field intensity by magnetometers to observe variations in ionospheric currents. Today, the INPE leads a series of space activities, including space science and space weather, and has facilities covering most of the territory of Brazil, with sites in Santa Maria (RS), São Martinho da Serra (RS), São José dos Campos, (SP), Cachoeira Paulista (SP), Cuiaba (MT), Fortaleza (CE), Natal (RN), São Luís (MA), and Belém (PA). More recently, on February 10th, 1994, the Brazilian government created the AEB, an autarchy associated with the Ministry of Science Technology and Innovations (MCTI) that was designed to formulate and coordinate the space policy in Brazil.

Also in the 1960s, institutional space research was established in Argentina. On December 29th, 1969 the IAFE was created, as a reorganization of the National Center of Cosmic Radiation (CNRC), which originated from the Laboratory of Cosmic Radiation of the National Atomic Energy Commission (CNEA) in the 1950s. IAFE was created by the University of Buenos Aires (UBA) and the National Council of Scientific and Technical Research (CONICET), with the main purpose of doing scientific research in the field of Space Physics and Astronomy, helping interested institutions to develop disciplines, contributing to researchers developing and teaching these disciplines, doing outreach in its fields, and maintaining scientific relationships with similar institutions of Argentina, and of other countries. The development of upper atmosphere research was especially emphasized in Argentina toward the middle of the 1970s, under the coordination of the "Programa Nacional de Radio-Propagación" formed from several institutions in Argentina, such as the "Instituto de Física" and "Instituto de Ingeniería Eléctrica", both from the National University of Tucumán

(UNT). During these early years, several researchers joined this branch of Geophysics in UNT, in particular Dr. José Roberto Manzano (1928–1999), who was an enthusiastic pioneer of this branch. In his honor, ALAGE created a prize with his name to be awarded to the best scientific work presented in its regular meetings. At the present time, UNT hosts several groups focused on studies of research lines associated with the ionosphere, climate change and space weather.

Planetary magnetism was another space science field that was driven by an enthusiastic pioneer in Argentina. Mario Acuña (1940–2009) was a major pioneer in this field. Born in the Córdoba province in Argentina, he earned a B. A. degree from the National University of Córdoba (UNC) in 1962. He then migrated to United States of America (USA) where he became a research scientist at National Aeronautics and Space Administration (NASA) Goddard Space Flight Center in the Space Plasmas and Planetary Magnetospheres Branches. Acuña was the principal investigator on several magnetometer experiments, such as the Pioneer 11 Fluxgate Magnetometer Experiment in 1973 and the Mars Global Surveyor Magnetic Field Experiment in 1994, the MESSENGER magnetometer. He received many professional awards, including election to the National Academy of Science, the Moe Schneebaum Memorial Award (the highest engineering award at Goddard), the NASA Exceptional Scientific Achievement Medal, and the NASA Distinguished Service Medal. Acuña played an essential role in the creation of ALAGE and his legacy inspired several Latin American science students and young researchers to choose space physics as their line of research. Recently, ALAGE created the Mario Acuña Award to recognize his contributions.

CONAE, created in 1991, is the Argentine space agency and, as such, coordinates the country's space activities. The mission of CONAE is to propose and implement a National Space Plan, which has the status of a Strategic Plan for space activities, establishing a policy of Argentine national priority. This long-term strategic plan states that all CONAE activities and projects must be focused on generating appropriate and well-timed spatial information for the Argentine continental and maritime territory in order to contribute to the optimization of socio-economic requirements of our country. This approach, common to most developing countries, which prioritizes applications that provide economic return over basic science, does not preclude activities related to climate change and space weather. Regarding the latter, three of the Scientific Applications Satellite (SAC) series, SAC-B, SAC-C and SAC-D, have carried space-borne instrumentation to measure solar X-rays and energetic particle distributions reaching low Earth orbit. CONAE also cooperates with other space agencies, like European Space Agency (ESA), National Center for Space Studies (CNES), and NASA on space weather and climate related missions, such as Van Allen Probes with NASA. Through a bilateral agreement, ESA has installed one of its three deep space antennae (DSA3) in the Province of Mendoza, and CONAE is the Argentine institution that manages 10% of its available time for use by the Argentine scientific community. A similar agreement is expected to be implemented with China's Launch, Tracking and Control Center (CLTC), for an antenna to be installed in the Province of Neuquen. Recently, in February 2015, CONAE signed an agreement with NASA to cooperate on space weather research. According to this agreement, CONAE will get the data directly from the Van Allen Probes mission using its equipment installed in its Space Center Teófilo Tabanera, in Falda del Carmen, Córdoba. This agreement will permit Argentina and Latin America to be strongly involved in several studies of space radiation, in particular to understand and quantify the fluxes of electrons and protons at the Van Allen radiation belts.

The beginning of institutional space research in Mexico was linked to the work of the pioneering physicist, Manuel Sandoval Vallarta (1899–1977) and his students from Mexico. Vallarta was a full time professor at the Massachusetts Institute of Technology (MIT), but used to return home during the holidays to teach at the Faculty of Sciences and the Institute of Physics of the UNAM (Mendoza, 1995). Eventually, Vallarta returned to Mexico in 1946 to work on cosmic rays research (Perez-Peraza, 2009). In 1962 a new group was created by Ruth Gall (1920–2003), with the aim of developing a program devoted to outer space science at the Institute of Geophysics of the UNAM (Gall-Sonabend, 2000). For her pioneering work in the field, ALAGE created a prize named after her.

The beginning of governmental space activities in Mexico is also related to Sandoval Vallarta, who in 1957 promoted the design and construction of rockets to study the upper atmosphere. In 1962 CONEE was created to advance the research, exploration and exploitation of the space by peaceful means. CONEE continued the development of rockets and upper atmospheric studies until 1977, when the commission was canceled by a presidential order. In the 1990s Ruth Gall funded an Interdisciplinary Group of Space Activities at UNAM, which eventually became the PUIDE. The program was established in 1992 under the direction of Alfonso Serrano and it built two micro-satellites named UNAM-SAT. Unfortunately, due to the economic limitations at that time, the PUIDE program was canceled in 1997. Finally the AEM was founded in 2010. The aim of the AEM is to coordinate the space activities in Mexico.

Recently, private Universities in Brazil also decided to form space research groups with activities related to space weather. The University of the Paraiba Valley (UNIVAP) started an ionospheric group in 1998 and one of their topics of interest is the response of the ionosphere to the geomagnetic storms. They have deployed ionosonde, all-sky imagers and Global Positioning System (GPS)[1]

[1] The GPS is a satellite system controlled by the USA and it is part of the Global Navigations Satellite System (GNSS).

receivers at several stations in Brazil, and recently Fabry-Pérot interferometers and magnetometers. The main purpose of the research being carried out there is related to the day-to-day variability of the dynamics in the upper atmosphere (mesosphere and thermosphere) and the electrodynamics in the ionosphere, during the high and low solar cycle, at equatorial region[2] and low latitudes.[3] In addition, the group also focused on ionospheric changes during geomagnetic storms as well as in the propagation of Travelling Ionospheric Disturbances (TID). Both of these are related to the current environmental conditions of space, and therefore, in our definition of space weather.

Considering all of the abovementioned institutions and their work and research, Latin America provided a substantial contribution to space science in the area of Solar Terrestrial Physics more recently called Space Weather. In the following subsections we highlight various research that we consider relevant to space weather, constrained to research groups within three Latin American countries (Argentina, Brazil and Mexico), which provide examples of local scientific evolution. The contributions from the research were organized in four general areas: solar, interplanetary medium, magnetosphere and geomagnetic field, and neutral and ionized atmosphere research.

2.1. Solar research

There are several reasons to state the reliable prediction of solar flares is still not possible. There is a lack of most appropriated measurements of the coronal loop rise (especially internally to the corona) and the magnetic reconnection physical details, as well as a lack of knowledge about the relative importance of relevant Magneto-Hydro-Dynamic (MHD) instabilities. Also, since the most energetic solar flares are usually related to Coronal Mass Ejections (CMEs), which have the potential to severely impact terrestrial technological systems (e.g., satellite operations and power grids) and safe human travel in space, studying solar dynamics is still an essential part of forecasting space weather.

Solar dynamics can be studied in several temporal and spatial scales: long term (solar cycle intensity) or short term (solar bursts leading to flares, CME, etc.), and the full solar disk (total irradiance) or the minutes of the arc (active regions). Therefore, solar research groups can carry out their research in several different ways. In Latin America, most of these studies have been done with ground instrumentation using both optical and radio observatories. Radio noise interference constrains radio observations so, in theory, a protected area like a crater or a valley would be ideal. Optical observations do not require such rigid radio spectrum protection, but they do have to deal with atmospheric distortions of the electromagnetic wave in the visible band, and it is essential to avoid the light pollution of the cities. So, the natural choice is to set an optical ground instrument on high altitude mountains near the Andes in South America.

Indeed, the ground-based solar instruments of remote sensing have been operational since 1999 in the Argentine portion of the 'El Leoncito' in the Altos Andes (details are provided in Section 3 of Denardini et al. (2016). Among the measurements and research carried out there, in the Astronomical Complex "el Leoncito" (CASLEO, formally created in 1983 as an agreement between CONICET and several Argentine universities, has been active since 1986), we highlight the Solar Submillimeter Telescope (SST) observations, which are relevant for particle acceleration processes and energy release diagnosis during solar flares (Cristiani et al., 2005; Giménez de Castro et al., 2013). In addition, the combination of coronal magnetic field modeling with SST observations has proven to be useful to understand how the submillimeter emission originates as well as to properly characterize the studied transient phenomena (Cristiani et al., 2007, 2008).

Two other solar telescopes, installed in the Félix Aguilar Astronomical Observatory (OAFA), Estación de Altura Ulrico Cesco, arose from collaboration between Argentina and Germany. These are the Mirror Coronagraph for Argentina (MICA, Stenborg et al., 1999) and the H-Alpha Solar Telescope for Argentina (HASTA, Bagala et al., 1999; Fernandez Borda et al., 2002). MICA is an internally-occulted mirror coronagraph with a plate scale of 3.6″ per pixel that images the solar corona at a nominal cadence of about 1 min between 1.05 and 2.0 solar radii in the Fe XIV line and in the continuum emission. MICA has produced results relevant to the origin of coronal eruptive phenomena in general (Stenborg et al., 2000; Bagala et al., 2001; Balmaceda et al., 2003; Costa and Stenborg, 2004; Borgazzi and Costa, 2005), but is now currently under maintenance. HASTA is a full-disk H-alpha imager, with a plate scale of about 2″ per pixel operating with a cadence of 90 s (in the patrol mode) and from 3 to 0.5 s (in the flare mode). The latter is especially suitable for the monitoring of flares and filament disappearances. Several studies have been carried out to understand the origin of flares, the evolution of associated Moreton waves, and the onset of CMEs benefitting from HASTA data (Luoni et al., 2007; Francile et al., 2013; Mandrini et al., 2014) or HASTA combined with SST (see previous references).

The recent astrophysical plasma group at the Institute for Theoretical and Experimental Astronomy (IATE) funded by CONICET and the UNC, located in the city of Córdoba, Argentina has recently started research related to solar and plasma physics. They have studied dynamic solar phenomena that can be triggered by CMEs. This is the case of Moreton waves (e.g., Francile et al., 2013) and the dynamic of supra-arcade down-flows (e.g., Cécere et al., 2012).

[2] In the present work, equatorial region is defined as the latitudinal band around the magnetic dip equator between ±3° and 5° magnetic latitude.

[3] There is no exact definition where the low latitudes upper boundary lies. In this manuscript it means the two latitudinal bands surrounding Earth from 3–5° to about 50° of magnetic latitude, in both Northern and Southern hemispheres.

Specifically, regarding the space weather initiatives in Argentina, the research groups are currently carrying out the generation of the solar magnetic field by dynamo mechanisms (e.g., Mininni et al., 2001), the heating of active regions in the solar corona (e.g., Gómez and Ferro-Fontán, 1988), and the analysis of solar ejective events and their interplanetary counterpart-phenomena, such as Magnetic Clouds (MCs), also mentioned in the literature as Coronal Mass Ejections (CMEs) since it is ejected from the solar corona, and Interplanetary Coronal Mass Ejections (ICMEs) when they manifested in the interplanetary medium. In the solar perspective, the earlier works in this line of research identified the CMEs associated with long-living Active Regions (ARs), considered their potentiality as sources of MCs, and evaluated the origin of the magnetic helicity ejected during the AR lifetimes (see e.g., the review by Mandrini et al., 2004). Following this line of research, several studies of particular solar events and their related interplanetary (IP) ones were developed based on the computation of MHD invariants in the solar surface and in the interplanetary medium (e.g., Dasso et al., 2003; Dasso et al., 2005a; Mandrini et al., 2005, 2007; Luoni et al., 2005; Dasso et al., 2006; Attrill et al., 2006; Nakwacki et al., 2011). In a different line, several studies were developed to forecast the time of arrival of CME-driven shocks. This technique takes advantage of the kilometric type II radio emissions to model and improve predictions (e.g., Dasso et al., 2009; Cremades et al., 2015). Most of the previously mentioned works have been done as part of collaborations with foreign research groups. Many other studies that focused on aspects relevant to space weather and that study geoeffective solar transients at different stages have been done by groups in Argentina. For example, some of these studies have focused on the erosion of ICMEs due to magnetic reconnection with solar wind ambient field (Dasso et al., 2006; Ruffenach et al., 2015), the evolution of MC from the solar eruption to 5 AUs passing by and encompassing Earth (Rodriguez et al., 2008; Nakwacki et al., 2011), the interaction between two ICMEs in the inner heliosphere and consequence on geoeffectiveness (Dasso et al., 2009), the expansion of magnetic clouds in the inner heliosphere and effects on Sun-Earth connection (Demoulin and Dasso, 2009a; Gulisano et al., 2010), the geoeffectiveness of CMEs launched near the solar limb (Cid et al., 2012), models for the global shape of magnetic clouds and for the surface of their driven shocks in the heliosphere (Janvier et al., 2015).

In Mexico, research in solar physics has mainly been developed by IGF/UNAM in Mexico City for several decades based mostly on theoretical models and data analysis and cover different fields. The long-term variation studies were conducted based on the data analysis of the sunspot number temporal series to study the evolution of the solar cycle (Otaola and Zenteno, 1983; Bravo and Otaola, 1989; Valdés-Galicia et al., 1996; Valdés-Galicia and Velasco, 2008). The short term solar phenomena like solar flares, energetic particles, energy transport and acceleration processes have been investigated by Perez-Peraza (1986) and Perez-Peraza et al. (1997), while energetic solar events involving gamma ray emissions were investigated by Pérez-Enriquez and Miroshnichenko (1999) and Miroshnichenko et al. (2000). Bravo (1995), Bravo and Stewart (1997) and Maravilla et al. (2001) have investigated the physics of the coronal holes and its relation to solar wind streams. Additionally, Bravo and Stewart (1995), Bravo et al. (1998) and Bravo and González-Esparza (2000) have used the potential field model to study and publish results related to the evolution of the solar magnetic field and coronal holes.

Mexican researchers also investigated the solar phenomena eruptive activity that may eventually drive the Earth magnetospheric and ionospheric variability, like the CMEs. The relationship between CMEs and the heliospheric current sheath have been studied by Mendoza and Perez-Enriquez (1993). Lara et al. (2003) studied solar radio burst associated with CMEs, and Lara (2008) analyzed source regions of CMEs on the solar surface. Aguilar-Rodriguez et al. (2005) established the characteristics of the spectra emission of type II radio burst driven by CMEs in the interplanetary medium. Also, Ontiveros and Vourlidas (2009) studied the coronal shock waves driven by CMEs.

Recently, several analytical studies have been developed to forecast the arrival time of CME-driven shocks, which is a problem critical to space weather forecasting. An empirical model to predict the arrival of CMEs to 1 AU was developed by the Mexican research group (Gopalswamy et al., 2000, 2003) while Cantó et al. (2005) presented a full 1-D hydrodynamic analytic solution of the kinematics of CMEs in the interplanetary medium. Corona-Romero and González-Esparza (2011) extended this formula to include shock waves, and Corona-Romero et al. (2015) applied the model to reproduce trajectories, arrival times and type II emissions driven by shock waves in the interplanetary medium.

Brazilian contribution to solar research has been historically carried out by ground-based observational astronomy studies, and for many centuries limited in the optical band, utilizing radio frequencies only in the middle of the last century. Solar research for space weather has been carried out mostly by radio astronomers. In addition to the research, INPE in particular has been leading instrumental development in radioastronomy. The instruments developed have been used for solar physics, space weather and cosmology (Elias et al., 2010). The first step was taken through the creation of the Itapetinga Radio Observatory (ROI) in Atibaia (SP) in 1974, employing a dish antenna 14-m wide (e.g., Takakura et al., 1983). This development allowed the ROI research group to work with wavelengths from centimeters to millimeters (18–90 GHz), while the rest of the world was working with the 21-cm wavelength. Recently, new solar monitors have been developed like the Brazilian Decimetric Array (BDA) and have been contributing to the international initiatives using SST just mentioned above.

Scientifically, we know that the solar atmosphere emission in the continuous radio spectrum is thermal in nature and it is associated with temperatures from 103 to 106 K at wavelengths from 1 mm to 1 m, respectively. The region of minimum temperature in the chromosphere and the Transition Region (TR) are included in the interpretations of the origin of the broadcast radio band. Therefore, the Brazilian solar research group's radio observation of the solar limb has contributed to the understanding of the existence of the transition region, or the temperature growth from the chromosphere through the corona studied based on the analysis of to the free-free continuous emission. The group noticed an interesting discrepancy between the distributions of temperature and density as a function of altitude in the solar atmosphere, especially the region where the TR occurs (e.g., Selhorst et al., 2005). There are references to the continuous radio emissions from higher heights that the resulting atmosphere model is based on. Furthermore, works on solar physics done by the Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG) at São Paulo University (USP) provided the characterization of inhomogeneities in the solar structure and causing interference in the distribution of brightness, as well as microwave and X-ray emission during an isentropic expansion, and its application in solar outbursts (SEPLAN, 1982).

Additionally, Brazil has contributed to radio observations completing the models of the solar atmosphere with observations from 1.4 to 400 GHz (e.g., Silva et al., 2005). Also, the observations obtained by the ROI at 48 GHz showed that the solar constant has a variation correlated with the solar emission at that frequency. This radio distance variation has a better correlation with bursts whose associated radio emissions were measured in the soft X-ray band, like those measured by the Geostationary Operational Environmental Satellite (GOES) satellites, than with the number of spots (Wolf number). Variations in the quiet sun associated with the solar activity cycle have been reported and monitored in ROI observation frequencies at 22.48 GHz. Although based on observations made in Japan in 17 GHz, a solar atmosphere model was developed by a Brazilian group.

2.2. Interplanetary Medium Research

After Forbush et al. (1949) and Forbush (1957), we know that a rapid decrease in the observed galactic cosmic ray intensity registered on Earth has a strong correlation with the presence of CME in the interplanetary medium. This decrease is due to the magnetic field associated with the solar structure sweeping part of the galactic cosmic rays away from the Earth's trajectory. What we have now established as one of the major phenomena in the space weather forecast was first investigated in Latin America as space research in its several different branches. Indeed, the early investigations of cosmic ray data in Latin America related to what we modernly call Space Weather were performed by Forbush (1938), when he was mostly interested in studying the geomagnetic disturbances. The early studies included cosmic ray data collected in an ionization chamber at Huancayo (Peru) along with the magnetic records collected at this observatory (Lange and Forbush, 1948).

In Mexico, as Perez-Peraza (2009) accounts, cosmic ray research dates back to the early 1930s with the pioneering work on the application of the cosmic ray theory to the magnetic momentum of the sun and galactic rotation (Vallarta, 1933, 1937; Vallarta et al., 1939, 1958), leading to the organization of the 4th International Cosmic Ray Conference, which was attended by Soviet scientists for the first time in the history of this event (an accomplishment during that period). The research on this field was a relevant contributor to the space science as can be confirmed by the publications following the pioneer works, like the subsequent studies related with cosmic rays measurements by the Mexico City detector and the configuration of the geomagnetic field performed by Gall et al. (1968, 1982) and Smart et al. (1969). Indeed, its significance still has an effect on Mexican researchers, as the interplanetary magnetic fields and cosmic rays propagation results published by Valdés-Galicia (1992) and the cosmic rays fluctuations and detectors at high altitudes reported by Caballero and Valdés-Galicia (2001) indicate. Recently, the cosmic rays studies were extended to Forbush decreases and interplanetary disturbances (Lara et al., 2005).

The ground-based space sciences instrumentation in Mexico also began in Cosmic Rays research. It has evolved since the early 1950s with the installation of a Simpson type neutron monitor. At the beginning of the 1960s, IGF/UNAM acquired a Carmichael Neutron Super Monitor equipped with six proportional counters. Javier Otaola and Jose´ Valdes took care of and modernized the neutron monitor station. In collaboration with Japanese scientists, José Valdes and his students installed a solar neutron monitor on Mt. Sierra Negra in the state of Puebla in 2004 (Valdés-Galicia et al., 2004). In 2013, as part of the Global Neutron Detector Network, the new Scintillator Cosmic Ray Telescope (SciCRT) was installed at the top of the Mt. Sierra Negra (Sasai et al., 2014). In 2015, the High Altitude Water Cherekov Gamma Ray Observatory (HAWC) was also inaugurated in the Mt. Sierra Negra, in a joint collaboration between a large number of universities and scientific institutions from Mexico and the United States of America (Pretz for the HAWC collaboration, 2015).

In addition to these studies, the IGF/UNAM group developed new research fields in interplanetary physics including solar wind dynamics, shock waves and the propagation of large-scale interplanetary disturbances (Balogh et al., 1995; González-Esparza et al., 1996; Aguilar-Rodriguez et al., 2011). Moreover, they started developing numeric simulations of interplanetary shock waves and ejecta (González-Esparza et al., 2003) to address the problem of the time of arrival of the aforementioned CME-driven shocks.

The IGF/UNAM research group working on interplanetary physics also started the development of scientific infrastructure. Silvia Bravo and J. Americo Gonzalez-Esparza developed the Mexican Array Radiotelescope (MEXART), the first radiotelescope with large area (about 10,000 m^2) in Latin America, to track solar wind disturbances applying the interplanetary scintillation technique (González-Esparza et al., 2004). The facilities developed at the MEXART site brought the opportunity to incorporate new space weather related instruments. These instruments included: a magnetometer, GPS receivers, a Callisto antenna, and a Schumann antenna. The construction and operation of the MEXART during the 2000s led to the development of a new group of heliophysics and space weather in Morelia. This was the first time that a research group in Mexico in space physics could collaborate from outside of Mexico City. The new group began to focus on research related to space weather.

With respect to the development of interplanetary medium research in Argentina, the IAFE played an important role as one of the first institutions dedicated to space physics. The first director of IAFE was Dr. Jorge Sahade, a distinguished astronomer. From 1976 to 1995, when Lic. Horacio Ghielmetti, ex-director of the National Center of Cosmic Radiation, was the director of IAFE, the level of researcher activities on cosmic rays in Argentina was enhanced. At that time, in order to interpret cosmic ray data as a source of high energy particles, these researchers studied the variation of the flux of cosmic rays with the magnetic latitude and different mechanisms for cosmic-ray propagation and diffusion through the atmosphere. After some evolution of CNEA groups (for more details of the early cosmic-ray research in Argentina, see Roederer, 2003 and Rovero, 2009), one clear branch of research emerged, which focused on space physics, mainly including cosmic rays of solar and galactic origin and their transport through the interplanetary magnetic field. Juan G. Roederer, Jose R. Manzano, and Horacio Ghielmetti were the three main researchers of this branch in Argentina. Several works arose from Latin American collaborations in that time, such as the collaborative work from Argentina–Brazil–Bolivia on the analysis of neutron monitor data (Roederer et al., 1961).

With the advent of the space era, several spacecraft dedicated to space weather were launched and a vast number of ground observatories were established. One of the goals of such observatories, like the Latin American Giant Observatory (LAGO) (Asorey et al. for the LAGO Collaboration, 2015), was to study the impact of the interplanetary conditions on the transport of galactic cosmic rays in the heliosphere and a better understanding of Gamma Ray Bursts by constraining their emission at high energies (Abreu et al., 2011). The transport properties of Cosmic Rays (CRs) before arriving to Earth are determined by the conditions of the interplanetary magnetic field. Therefore, the state of the heliosphere directly affects the flux of CRs at Earth. Also, when a CME is ejected from the Sun, and manifested in the interplanetary medium as an ICME, a well-known transient decrease of CR flux can be observed (i.e., the so-called Forbush decrease).

At UBA and IAFE in Argentina, there are also activities concentrated on theoretical and numerical modeling of a number of space weather and space plasma structures and flows. These activities are focused mainly on the solar link and interplanetary structures, (e.g., Dasso et al., 2005b) the magnetic structure and dynamical evolution of ICMEs and interplanetary magnetic clouds (e.g., Dasso et al., 2003, 2012a; Demoulin and Dasso, 2009a), the magnetic reconnection and erosion in ICMEs (Dasso et al., 2006), the geoeffectiveness of the ICME-ICME interaction (e.g., Dasso et al., 2009), and the occurrence of magnetic reconnection at the Earth's magnetopause (e.g., Morales et al., 2005). More recently, these activities have been extended to include models for the dynamical evolution of magnetic clouds structure (Gulisano et al., 2010; Demoulin and Dasso, 2009a; Nakwacki et al., 2011), and models for the local and global shape of ICMEs and their driven shocks (e.g., Demoulin and Dasso, 2009b; Janvier et al., 2015). Properties of Ultra-Low Frequency (ULF) waves in foreshock structures (e.g., Andrés et al., 2013) in non-magnetic objects such as Mars, the interaction of the solar wind with their ionospheres giving rise to the so-called induced magnetospheres, and properties of proton cyclotron waves arising upstream of the bow shock of Mars (e.g., Romanelli et al., 2013) and Titan (e.g., Bertucci et al., 2008) are also currently being studied. Studies of the structure of the Forbush decrease and its relationship with magnetic cloud properties is a recent branch of research in UBA (Masías-Meza and Dasso, 2013).

2.3. Magnetosphere and geomagnetic field research

It is well known that the CME are one of the most pronounced phenomena from solar origin impacting the space weather. Also, it is well documented that CMEs are the causative effect of the geomagnetic storm (Gonzalez et al., 1994; Gonzalez and Burch, 2012). Indeed, geomagnetic storms are normally described in terms of the effects measured by ground magnetometers due to the physical effects caused by strong perturbations to the interplanetary conditions near Earth, such as CMEs and their driven shock arrival. An initial phase is associated with interplanetary forcing caused by a southward magnetic field combined with fast solar wind speed, which mainly raise an induced dawn-dusk electric field in the magnetopause, causing magnetic reconnection and producing connectivity between geomagnetic and interplanetary magnetic field lines (i.e. merging these two different topological fields). This process allows the penetration of solar material through the terrestrial environment and produces changes to the topology of the outer geomagnetic field, which in turn change the trajectory of charged particles. After a complex sequence of dynamical processes in the magnetosphere, a significant enhancement of energetic charged particles occurs (which in turn produces an increase of different systems of space currents) with a consequent increase of the induced geomagnetic field that can be observed from ground detectors. Then there is a recovery phase due to decay of these space currents produced by a combination of charge-interchange and wave-particle interaction processes (Gonzalez et al., 1994). A consequent precipitation of energetic particles into auroral regions and/or precipitations to a lower height like in the South American Magnetic Anomaly (SAMA) regions can frequently happen during these geospheric perturbations (Prolss, 2004). The decay time of intense geomagnetic storms, associated with enhancements of the ring current system, can last from about 10–18 h (Dasso et al., 2002).

In Brazil, the INPE's research group started studying two fundamental processes associated with inner magnetosphere dynamics and their effects in the SAMA in 1980. Those processes refer to particle precipitation in the SAMA during intense geomagnetic storms and high-altitude atmospheric electric field perturbations at the SAMA due to particle precipitation. For this objective, the group used experiments on board balloons, with payloads constructed at INPE to measure X-rays from the precipitating electrons and double-probe electric field sensors to study the atmospheric electric field modification due to particle precipitation. A summarizing paper about the main observations and implications for the SAMA, obtained in this research activity, can be found in Gonzalez et al. (1987).

Afterwards, from 1986 through 2000 the magnetospheric research group in Brazil devoted efforts to studying the external magnetosphere, especially in association with the topic of magnetic storms, using external collaborations obtained mainly from the Jet Propulsion Laboratory/NASA of Pasadena, USA. The group published more than 100 papers with this research topic, organized several international Workshops and edited a book entitled "Magnetic Storms" (Tsurutani et al., 1997). Maybe, one of the most representative contributions from Latin America during this period was "What is a Geomagnetic Storm" (Gonzalez et al., 1994), which has been extensively cited (with more than 1000 citations as of 2014). Two other important contributions of this time period are: Tsurutani and Gonzalez (1987) and Clúa-Gonzalez et al. (1993).

During the first decade of this century, the research on magnetosphere carried out in Brazil extended to the solar physics covering both magnetospheric and heliospheric phenomena investigation related to the solar–terrestrial interactions, and also with the interest of extending research topics to interplanetary physics and solar activity. One important experimental project that started during this time period is that concerning the measurements of cosmic ray-muons in collaboration with a Japanese research team (Silva et al., 2007). The research group also organized an international Conference in Brazil in conjunction with NASA and within the International Living With a Star (ILWS) program in October 2010, involving topics in Solar–Terrestrial Physics. As a result of that Conference the group edited a special issue of the Journal of Atmospheric and Solar–Terrestrial Physics, with 40 articles and also edited a book published by Springer (Gonzalez and Burch, 2012). The publication numbers during this time interval was kept around 100 papers, but the most significant fact was that the number of research scientists had grown to 5 and several more graduate students joined the research field. Representative papers for this time period are: Dal Lago et al. (2004), Tsurutani et al. (2003, 2006), Gonzalez et al. (2007, 2011), Echer et al. (2008), Chian et al. (2010) and Domingues et al. (2013).

In Mexico, the magnetospheric physics research has focused on data analysis and the numerical modeling of the upstream bow shock waves and kinetic disturbances as part of collaborations with foreign research groups (Blanco-Cano and Schwartz, 1997; Blanco-Cano et al., 2006, 2009; Kajdic et al., 2011). On the other hand, there is research which also addresses problems related directly to space weather such as the geoeffectiveness of the heliospheric current sheet (Mendoza and Perez-Enriquez, 1995) and interplanetary signatures causing geomagnetic storms (Ontiveros and González-Esparza, 2010).

Important effects associated with geomagnetic storms have been studied in Argentina as well, such as the induction of currents at ground level due to the ionospheric currents caused by the magnetic storm. These Ground level Induction Currents (GIC) can contribute to the increase in corrosion of underground pipes, which is one of the main problems in oil and gas pipelines. In Argentina there are very long pipelines transporting gas and oil, and there is a group at UBA that does research on this kind of problem (Osella and Favetto, 2000; Osella et al., 2002). During days of high geomagnetic activity, excessive GIC are channeled along the pipes overriding the protective actions. By using a magnetic data recorder with magnetometers in Argentina, studies have been done on the effects of geomagnetic activity on pipelines (e.g., Gianibelli and Quaglino, 2007; Gianibelli et al., 2008). A group at UBA started to make studies of radiation at the SAMA using radiation data from the Influence of Space Radiation on Advanced Components (ICARE) experiment (Lanavere et al., 2015). The experiment ICARE, aboard the Argentine satellite SAC-D, measures electron and proton fluxes in the 250 keV to 4 MeV energy range and in the 8–120 MeV energy range, respectively.

2.4. Neutral and ionized atmosphere research

From the space weather research and operations perspective, we know that one of the big issues to be investigated both experimentally and theoretically is the plasma bubble trigger and its development (theoretically but connected to ionospheric physical models). Additionally, there is no current model, even with data assimilation techniques, that is able to successfully forecast the development of the plasma bubble (Schrijver et al., 2015).

In this field, one of the important contributions to space science, which will later become a great contribution to the understanding of one of the most relevant space weather phenomena in low latitude Latin America, was the work related to plasma bubbles published earlier in the 1980s (Sobral et al., 1980a,b, 1981). Before these studies based exclusively on the airglow measurements of the atomic oxygen line (630 nm), nobody had ever reported plasma bubbles in Latin America. Also, they realized that such phenomena were responsible for strong interference in trans-ionospheric communication after visiting a Brazilian Telecommunication Company (José Humberto Andrade Sobral, Private Communication). Today, the importance of the ionized atmosphere in the diverse space application systems of our day-to-day life is fully recognized. Examples of these space application systems include space based navigation system, telecommunication and global positioning systems by GNSS satellites. The role of the ionized atmosphere is especially important as we know that plasma bubbles can degrade the signal-to-noise ratio of any radio signal crossing the ionosphere.

Actually, since the ionosphere is an integral part of our space environment, the large variability that characterizes the ionosphere is a manifestation of the changes in space weather. The research conducted at INPE also recognizes the fact the ionospheric domain of the space environment is highly responsive to variability in the Sun, and therefore the Solar and ionospheric weather systems are closely linked. Further, the equatorial and low latitude ionosphere over Brazil possesses characteristics that are distinctly different from those of other regions of the globe, due to the global maximum of plasma concentration associated with the equatorial ionization anomaly. It is also subject to large modifications due to the SAMA that encompasses this region, where the total intensity of the Earth's magnetic field is the weakest permitting enhanced atmosphere-magnetosphere interaction resulting in energetic particle precipitation capable of modifying the ionospheric conductivity distribution in significant ways.

Indeed, the ionospheric research in Brazil started at INPE at its very beginning as the institute was founded in 1961. The installing of diversified ionospheric diagnostic instruments and the setting up of observatories in different parts of Brazil began in the 1970s. INPE's major ionospheric observatory at Cachoeira Paulista (SP) became operational in 1973, starting with routine ionospheric observations using ionosondes and airglow photometers. This was followed by the setting up of the ionospheric observatory in Fortaleza (CE), where an ionosonde and a magnetometer began operating in 1977. Ionospheric investigations using sounding rockets was initiated by INPE in collaboration with the Brazilian Technical Center of Aeronautics (CTA) which launched a SONDA-3 rocket from the rocket launch base in Natal (RN) in 1984, which was followed by additional launches from the Brazilian equatorial launch base in Alcântara (MA), as well as in Natal (RN). These rockets carried a high frequency capacitance probe and Langmuir probe for measuring electron density and temperature up to an altitude of 600 km. The equatorial space observatory at São Luís (MA) near the dip equator began operating in the early 1990s with the installation of a digital ionosonde (Digisonde) and two magnetometers, followed by two back-scatter radars (one of them developed at INPE), operating in the Very High Frequency (VHF) range, as well as GPS receivers, enhancing the observational network. The development of the extensive observational network to monitor ionospheric weather variability over Brazil took a long stride with the setting up of conjugate point ionospheric observatories, in the northern and southern regions of Brazil. This development now continues under the umbrella of the Embrace/INPE Space Weather Program.

Scientifically, the early investigations on the ionospheric total electron content distribution using low Earth orbiting satellites, and equatorial ionization anomaly, Spread-F irregularities (due to the presence of plasma bubble), and sporadic E layer phenomenon in the SAMA, that were based on ionosonde observations, have resulted in important publications (de Mendonça, 1965; Abdu and Batista, 1977; Batista and Abdu, 1977). Almost simultaneously, the airglow observation research began in Brazil at INPE in 1971 with a simple 2-channel airglow photometer measuring the atomic oxygen 557.7 nm and 630 nm emissions. In early 1973, the photometer detected fast depletions of OI 630 nm during the night, which were later recognized as plasma bubbles. In the late 1970s, meridional scanning photometers observed the longitudinal structure of the 630 nm emission in the ionosphere. In the 1980s, improvement of the airglow photometer (multi-channel photometers) made it possible to measure several emissions simultaneously. OH and O_2 rotational temperatures in the mesosphere, atomic oxygen 557.7 nm, 630 nm and 777.4 nm emissions in the ionosphere were successfully observed and allowed the study of the dynamics in the upper atmosphere by airglow.

Vertical profiles of the airglow emissions were observed by photometers on board rockets in the late 1980s to 1990s (Takahashi et al., 1996). In 1990, scientific interests in the airglow observation extended to the Atmospheric Gravity Waves (GW) in the mesosphere and plasma depletions in the ionosphere (Sobral et al., 2002) and the development of airglow imager using digital Charge-Coupled Device (CCD) camera started in the late 1990s. The first airglow images observed at Cachoeira Paulista (SP) were reported (Batista et al., 2000; Medeiros et al., 2001). Characteristics of plasma bubbles have been extensively studied since then, especially by the 630 nm imager (Santana et al., 2001). GW in the mesosphere and in thermosphere has also been studied (Klausner et al., 2009; Medeiros et al., 2004). In 2000s, airglow observations focused the study in dynamic coupling of the atmosphere from the troposphere to ionosphere.

Afterwards and presently, the aeronomy research at INPE covers wide range of distinct topics, whose investigations are pursued using data collected from a ground-based observational network consisting of the different instruments mentioned above, satellite data obtained through collaboration with international scientific groups, data from rocket borne experiments, and theoretical, numerical and empirical modeling of the ionospheric processes. The investigations focus on the following topics: (1) electrodynamics and plasma structuring of the equatorial-low latitude ionosphere, including investigations of plasma bubbles and electrojet irregularities; (2) atmosphere–ionosphere modifications under space weather disturbances, focusing on the responses of the ionosphere to magnetospheric and solar storms; (3) atmosphere–ionosphere system and upward propagating waves from tropospheric sources, focusing on the modification of the ionospheric phenomena as a result of vertical coupling due to upward propagating tides, planetary waves and GW; and (4) SAMA impact on the equatorial ionosphere under space weather disturbances, when large modifications of ionospheric conductivity occur that impact the electrodynamics of the equatorial ionosphere including the generation and dynamics of plasma bubbles.

Regarding the electrodynamics and plasma structuring of the ionospheric F region, Abdu et al. (1981) and Batista et al. (1986) provided the first observational evidence that the geomagnetic field declination angle can control equatorial Spread-F/plasma bubble irregularity developments. Through sunset terminator alignment with the magnetic meridian, this provided the first sound basis for explaining the longitude dependent seasonal variation in the equatorial plasma bubble/spread F irregularity occurrences on a global scale. Recently, Abdu et al. (2009) provided quantitative evidence that GW induced wave oscillation in evening F layer heights could serve as seed perturbation for the development of plasma bubble/Spread-F irregularities in the post sunset equatorial ionosphere. With respect to the ionospheric E region, Denardini et al. (1999) provided the first observations of the Equatorial Electrojet (EEJ) plasma irregularities since the earliest studies using the ionosondes. In the 2000s, several other aspects of the EEJ were also investigated based on the coherent radar technique like: the vertical distributions of the irregularities type 1 and type 2 (Denardini et al., 2003), the day-to-day variabilities of the EEJ under auroral activity and quiet conditions (Denardini et al., 2004), its seasonal characterization (Denardini et al., 2005) dependence with the solar flux (Denardini et al., 2015); as well as the transition from day to night (Denardini et al., 2006), when the pre-reversal electrodynamic enhancement lifts the whole ionosphere leading to plasma bubble formations.

With respect to the ionosphere modifications under space weather disturbances, Abdu et al. (2008) and Santos et al. (2012) have helped clarify the diverse nature of the low-mid latitude ionospheric modifications. For example, they have provided the first evidence that suggests prompt penetration magnetospheric electric field of eastward polarity occurring in the post sunset equatorial ionosphere could generate equatorial plasma bubbles, and that they could propagate zonally westward (instead of their normal eastward motion), and over-shielding electric fields can suppress the evening pre-reversal vertical drift and plasma bubble development. At the same, time Denardini et al. (2011) showed that interplanetary magnetic field/electric field structures with scales of about 1 h seem to easily penetrate the ionosphere, explaining the filtering of some magnetic disturbances at low latitude.

Also, specifically about the E regions responses to storm time, significant progress has been made by Denardini et al. (2009) to explain the behavior of the plasma irregularities (driven by electric field) to the disturbance dynamo, as well as by Shume et al. (2010, 2011) and Guizelli et al. (2013) who explained the regional differences in Latin America. Resende and Denardini (2012) and Resende et al. (2013) demonstrated that the E regions could be directly affected by the X-ray flow due to solar flare by investigating the evolution of the electron density during solar events in solar cycle 23.

Regarding the upward propagating waves from tropospheric sources to the ionosphere, the works published by Abdu et al. (2006), Aveiro et al., 2009a,b, Kherani et al. (2009), Takahashi et al. (2005, 2010) and Abdu et al. (2015) have made significant contributions to our understanding of the atmosphere–ionosphere coupling processes, driven by upward propagating atmospheric waves, that operate in the plasma structuring mechanisms that may lead to the formation of wide ranging scale sizes of plasma irregularities, and plasma bubbles, in the equatorial ionosphere or just modulate the E region structures.

Finally, with respect to the SAMA impact on the equatorial ionosphere under space weather disturbances, several publications from the Brazilian group (Abdu and Batista, 1977; Batista and Abdu, 1977; Abdu et al., 1998, 2005; Moro et al., 2012a, 2013) provided evidence that energetic particle precipitation is a regular source of E-layer ionization in the SAMA region under magnetic quiet conditions and that its enhancement occurred during space weather disturbances. These results also showed impact of the SAMA on the electrodynamic processes of the equatorial ionosphere through generation of enhanced conductivities that modify plasma bubble development, vertical and zonal plasma drift. The studies revealed occurrences of abnormally large vertical plasma drifts and anomalous reversals westward of the zonal plasma drift. In summary, the research group in Brazil has been contributing to the international community of aeronomy in the space weather related areas such as: atmospheric GW and planetary waves and plasma bubble monitoring.

Argentine research groups have also played an important role in the neutral and atmospheric research, leading to the creation of the Argentine Network for the Study of the Upper Atmosphere (RAPEAS)[4] in 2011. It currently has 57 researchers in 19 research groups from 15 institutions in 5 provinces (Tucumán, San Juan, Mendoza, Buenos Aires, and Tierra del Fuego, Antártida e Islas del Atlántico Sur). The main objective of the network is to consolidate the Argentine scientific-technological community devoted to the study of the upper atmosphere of the Earth and its space environment by promoting the development in Argentina of instrumental observation based on radar technology. This network also aimed to encourage and strengthen research and technological developments to maximize the benefit to Argentina of instruments already installed and projected to be installed. They also aim to contribute to the sustainability of human resources and to optimize the use of installed and projected instrumental resources through the collaborative efforts of different groups and institutions that make up the network. They routinely survey the observational systems available in Argentina to make their information available to the network and to disseminate and share information through a website. Also, they optimize the use of satellite information produced under the National Space Plan to identify relevant issues that offer competitive advantages for the Argentine community and promote development through collaborative efforts. In addition, they link RAPEAS with other international networks to optimize the recording, analysis and modeling of changes in the magnetic field produced by sources of external and internal origin.

Argentina hosts several institutions and initiatives in regard to the experimental sounding of the upper atmosphere and ionosphere led by research groups established there. As an example, researchers from the National University of La Plata (UNLP) have studied different properties of the ionosphere during disturbed magnetic conditions (Azpilicueta and Brunini, 2012; de Abreu et al., 2014). This group also actively participated in several of the first publications on the use of GPS receivers for the remote sensing of ionospheric properties (Brunini et al., 2004). Another example comes from the Telecommunications Laboratory and from the Laboratory of Ionosphere at the UNT. These groups have been working on several research projects in collaboration with the Center for Upper Atmosphere and Radio propagation Research (CIASUR, 26.8 S; 65.2 W) at the National Technological University (UTN). Instead of installing instruments to create new networks, their importance relies on being part of several existing networks of instruments (details are provided in Section 3 of Denardini et al. (2016). Among the instruments they host, there are several that are related to ionospheric phenomena associated to space weather. The main deployed instruments are: (1) an Advanced Ionospheric Sounder (from AIS-INGV) designed both for research and for routine service of High Frequency (HF) radio wave propagation forecast; (2) a modified dual-frequency GPS receiver for ionospheric scintillation and Total Electron Content (TEC) monitoring configuring a Double Frequency GPS Receiver System (from AIS-INGV) to monitor transient effects such as the ionospheric scintillations in phase and amplitude, and the slant TEC; (3) a Multi-static HF Doppler Radar (from API-Czech Republic) to observe atmospheric GWs and ionospheric irregularities; (4) a Riometer single Channel (from Japan) to study the ionospheric opacity and high energy precipitation particles; and (5) a single frequency GPS receiver (from UNT) to measure ionospheric scintillation.

In terms of joint research, besides the traditional research-to-research collaborations several institutions from Argentina and Brazil actively contribute to the GNSS Research and Application for the Polar Environment (GRAPE)[5] group, a joint expert group of Scientific Committee on Antarctic Research (SCAR)[6] focused on space weather studies. Among them, we list the UNLP, the Institute of Astronomical Sciences, Earth and Space (CONICET/ICATE), the Argentine Antarctic Institute (IAA), UNT, the Paulista State University (UNESP), the Mackenzie University, and INPE.

In Mexico, the ionospheric research at IGF/UNAM was initially focused on the interaction of solar wind and other planets (Perez-de-Tejada and Dryer, 1976; Perez-de-Tejada, 1986, 1992, 1999). However, their recent studies address ionospheric disturbances and interplanetary scintillation (Carrillo-Vargas et al., 2012; López-Montes et al., 2012; Rodríguez-Martínez et al., 2014). Ionospheric studies related to space weather phenomena over the Mexican territory are a window opportunity of significant relevance. The recent available networks of GPS stations along the Mexican territory bring an opportunity to develop vertical TEC maps in almost-real time. Another exciting opportunity to investigate ionospheric disturbances in Mexico comes from the new Schumann station at the MEXART site, which studies Schumann resonance frequencies (Sierra et al., 2014).

2.5. Development of solar–terrestrial interactions models

2.5.1. Cosmic rays modeling

Ground observatories of cosmic rays can measure fluxes of secondary particles created in extensive air showers in the terrestrial atmosphere. Furthermore, the trajectory of primary cosmic rays that initiate a shower undergo significant deviations due to the presence of the geomagnetic field, and, depending on their energy, cannot reach certain places. Therefore, it is necessary to consider the effects of the geomagnetic field on primary cosmic rays, and the cosmic rays shower due to interactions with components of the atmosphere. As an example, two well established numerical models are used in the frame of the work of researchers (in

[4] Available online at: http://www.rapeas-conicet.gov.ar/.

[5] More information available online at: http://www.grape.scar.org/.

[6] More information available online at: http://www.scar.org/.

the Centro Atómico Bariloche, UBA and IAFE) linked with the following international collaborators: The Pierre Auger Observatory [an international observatory located in Argentina (The Pierre Auger Collaboration, 2015)] and LAGO [a Latin American network of cosmic rays detectors (Asorey et al. for the LAGO Collaboration, 2015)]. These two numerical models are: Magneto-Cosmic and COsmic Ray SImulations for KAscade (CORSIKA). Magneto-Cosmic is a model used to simulate (it is a particle tracing code) the motion of primary particles in the geomagnetic field, based on Geant4, which allows the computation of the trajectory of charged particles, taking into consideration advances in geomagnetic field models like the International Geomagnetic Reference Field (IGRF) model and the near magnetosphere model with a dawn-dusk asymmetry developed by Tsyganenko (2002). Several simulations for the site in Latin America using this model have been published (e.g., Masías-Meza and Dasso, 2014). On the other hand, CORSIKA is a numerical code for the simulation of cosmic ray air showers (Heck et al., 1998). Using CORSIKA simulations in conjunction with the previously used models, the main range of energies observed with the scaler mode of the Auger observatory was determined (Dasso and Asorey for the Pierre Auger Collaboration, 2012b).

2.5.2. Magnetospheric modeling

The physical processes occurring in magnetized plasmas can vary at different space–time scales in the Sun–Earth system. Therefore, comprehensive MHD three-dimensional (3D) models are powerful tools that can help us understand how changes in the interplanetary and solar wind plasma may affect the magnetospheric plasma dynamics. They can fill the gaps left by observations, due to the restricted satellite orbits, and expand our knowledge about the physical processes during space weather events (Gombosi et al., 2000). The MHD theory deals with the macroscopic energy conversion governing the global configuration, that is, the physical processes involved in the conversion among the magnetic, kinetic and thermal energy.

The first MHD simulations date back to the 1970s and were used to describe the interaction between the solar wind and the Earth's magnetosphere (Leboeuf et al., 1978). From the 1980s until the present day, many research groups have been developing their own MHD 3D models, aiming to describe self-consistently the coupling between different regions of the geospace, for example: the Ogino model (Ogino et al., 1986, 1994; Matsumoto and Omura, 1993), the Grand Unified Magnetosphere-Ionosphere Coupling Simulation (GUMICS-4) model (Janhunen et al., 2012), the Lyon–Fedder–Mobarry (LFM) model (Lyon et al., 1981, 2004), the Space Weather Modeling Framework (SWMF) model (Tóth et al., 2005; Gombosi et al., 2001), the Open General Circulation Model (OPenGGCM) (Raeder et al., 2008), and the Piecewise Parabolic Method with a Lagrangian Remap (PPMLR-MHD) model (Zhang et al., 2013).

In Brazil, MHD simulations have been used as tools for the development of applications for Earth magnetosphere modeling, leading to Master and PhD theses in the Space Geophysics Graduate Program at INPE (Cardoso, 2006; Jauer, 2010). One important aspect during magnetic storms is the entrance of energy brought by solar wind to the magnetosphere. MHD simulations allow us to evaluate the entrance of this energy and also to verify the response of the magnetosphere to this change. For example, MHD simulations have been used to study magnetospheric energetics during High Intensity ($AE > 1000$ nT), Long Duration ($T > 2$ days) Continuous Auroral Activity (HILDCAA) showing that the plasma parameters (pressure, electric field and velocity) in the Earth's plasma sheet are delayed by about 15 min from the interplanetary magnetic field variation (Gonzalez et al., 2006). Jauer (2014) used MHD simulations to study the dynamic of the dayside magnetopause plasma flows and the energy content of Earth's magnetotail. All of the dayside magnetic reconnection global effects were analyzed through different Interplanetary Magnetic Field (IMF) orientations and solar wind plasma parameters simulations, performed by the 3D MHD global Block Adaptive Tree Solar wind-Roe-Upwind Scheme (BATS-R-US) model (Gombosi et al., 2000), which is now part of the SWMF. MHD models have been also used to simulate CMEs and their evolution in the low corona (Loesch et al., 2011).

Currently, the Brazilian group for the magnetosphere and heliosphere (MAGHEL) study at INPE is starting to use the Global 3D MHD SWMF model, developed and provided by the Center for Space Environment Modeling (CSEM) at the University of Michigan. Today the SWMF model is the state of the art in terms of three-dimensional of numerical models MHD; it allows the attaching of different regions of the Sun-Earth system, solving multiple scales involved (Tóth et al., 2012).

The same occurs in Argentina, where research groups at UBA, IAFE, and UNT are starting to use the SWMF at different stages of the Sun–Earth coupling, to study eruptive coronal structures (IAFE group), their interplanetary dynamical evolution (IAFE and UBA groups), their effects on different levels of the terrestrial environment (UBA and UNT groups), and the propagation of particles (UBA and IAFE groups). At IAFE and UBA, several academic numerical models to study basic physical processes, such as turbulence and solar dynamo, and magnetic reconnection, are being developed and run in high performance computers, such as clusters with a significant number of processors, which allow the resolving of small-scale processes.

2.5.3. Ionospheric modeling

Historically, Argentina and Brazil have actively contributed to the development of the International Reference Ionosphere (IRI) model, a project jointly established in 1968 by COSPAR and the International Union of Radio Science (URSI). The Latin American contributions to the

IRI model have been presented in IRI Workshops and COSPAR assemblies (e.g., Batista and Abdu, 2004; Mosert et al., 2007; Souza et al., 2010; Nogueira et al., 2013a). In addition Argentina has participated in the IRI Task Force Activities carried out in the International Centre of Theoretical Physics in Trieste, Italy from 1994 to 2004 and the IRI 2006 Workshop organized in Argentina with the participation of experts from several countries.

The IRI is an empirical standard model of the ionosphere which is widely used to predict and mitigate the significant effects that the ionosphere has on the performance of communication and global positioning systems. The model is designed to provide vertical profiles of the main ionospheric parameters (electron density, electron temperature, ion temperature, and ion composition) in the altitude range from about 50 km to about 2000 km, as well as the electron content for suitably chosen locations around the globe, hours, seasons, and levels of solar activity. It provides monthly averages for the non-auroral ionosphere for magnetically quiet conditions. The major data sources are the worldwide network of ionosondes, the powerful incoherent scatter radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin), the ISIS and Alouette topside sounders, and in situ instruments on several satellites and rockets. The IRI is updated annually taking into account experimental evidence presented during special IRI Workshops and during COSPAR general assemblies. From its first formulation, several steadily improved editions of the model have been released including important changes such as an improved representation of the electron density in the region from the F peak down to the E peak with a better description of F1 layer occurrence statistics and a more realistic description of low-latitude bottom-side thickness, the inclusion of a model for storm-time conditions, the inclusion of an ion drift model, two new options of the electron density in the D region, and most importantly, an improved model for the topside electron temperatures. The project has formed an International Working Group (a team of experts representing the different ground and space measurement techniques and the different countries interested in ionospheric research) in which Argentina participates actively with two members who joined the group in 1993. More information can be found in the IRI home page.[7]

The space research based on ionospheric physical-based models started in Brazil only in the early 1990s. However, it was only with the engagement of PhD students within international research groups that the modeling activity really developed (Souza, 1997). Since the ionospheric research was well developed in Brazil at that time, it was a natural choice that the model to be tackled was the Sheffield University Plasmasphere–Ionosphere Model (SUPIM). It was the first principles model of the ionosphere and plasmasphere of the Earth that has been developed over the past three decades (Bailey and Sellek, 1990; Bailey et al., 1993; Bailey and Balan, 1996; Souza et al., 2000; Santos, 2005; Souza et al., 2010). In the model, the equations of continuity, motion and energy balance, both time dependent and coupled, are solved along the magnetic field lines closed to calculate the values of density, flow and temperatures of electrons and ions O^+, H^+, He^+ N_2^+, O_2^+ and N^+. SUPIM includes more accurate representations of the Earth's magnetic field, which is an eccentric dipole. In fact, the magnetic field is obtained by displacing a dipole from the center of the Earth by a distance of 500 km in the direction of 21° N, 147° E and the axis cutting the surface of the Earth around 82° N, 90° W and 75° S, 119° E (Fraser-Smith, 1987). The eccentricity, of course, makes the magnetic coordinate system different than the geographical area. The model includes numerous physical and chemical processes. The main ones are: the production of ions due to solar EUV radiation, the production and loss of ions due to chemical reactions between the ionized and neutral constituents, and thermal ambipolar diffusions, ion–ion collisions and ion–neutral particle, thermospheric winds, electromagnetic ($E \times B$) drift, thermal conductivity, heating photoelectric frictional heat and a large number of local heating and cooling mechanisms (Bailey et al., 1997).

The next steps in the evolution of knowledge assimilations to allow the full understanding of the SUPIM code were taken between 1997 and 1999. It also happened by evolving personal exchange, this time with a post-doctoral researcher at the University of Sheffield. Others important steps in expanding the model coverage were also taken based on personal exchange (Santos, 2005; Santos et al., 2005). However, despite some limitations regarding the full representations of the observed phenomena by first principles models like SUPIM, the use of this model in space science has proved its value. By adjusting the model it was possible to support the physical explanations for the observation of the ionospheric F3 Layer (Batista and Abdu, 2004) and for the four peak structure seen in the global TEC maps (Nogueira et al., 2013b).

3. Pushing space weather forward in Latin America: selected research

During the past three decades, several research groups in Argentina and Brazil developed studies on magnetic reconnection and turbulence in the corona, the heliosphere and the magnetosphere. In Argentina, IAFE and UBA research groups activities included topics on turbulence in the solar corona (e.g., Gómez and Dmitruk, 2008) and in the solar wind (e.g., Dasso et al., 2005b; Ruiz et al., 2011, 2014; Andrés et al., 2014), on coronal geoeffective structures (e.g., Mandrini et al., 2005; Cremades et al., 2011), on magnetic reconnection at the magnetosphere (e.g., Morales et al., 2005) and in the solar wind (e.g., Dasso et al., 2006, 2007). The Brazilian research on magnetospheric and heliospheric phenomena has given special attention to the study of the cosmically important

[7] Available online at: http://iri.gsfc.nasa.gov.

process of Magnetic Reconnection, since that topic had been initially followed by the founder of this research group when he was a graduate student at the University of California-Berkeley. A representative paper of that initial study was the first published Model on magnetic reconnection at the Earth's magnetopause (Gonzalez and Mozer, 1974), which has also been extensively cited up to today. Regarding the topic of Magnetic Reconnection, the group organized an international Workshop at INPE in March 2014, with the presence of more than 40 invited scientists from abroad and about 120 participants. As a result of that Workshop, Springer published the Book "Magnetic Reconnection: Concepts and Applications" (Gonzalez and Parker, 2016), which includes the results published by Cardoso et al. (2013), Koga et al. (2014), and Ojeda et al. (2014). Additionally, since 2014 a new research project has started in the group to study solar magnetic fields using a ground telescope, which will be constructed in Brazil in collaboration with research groups from Germany and the USA.

The LAGO collaboration has started to develop its LAGO-Antarctic project, which plans to install a cosmic ray detector at the Marambio Antarctic base (64° 14′ 27.65″S, 56° 37′ 36.31″W) in Argentina (Dasso et al. for the LAGO Collaboration, 2015), where due to the low rigidity cutoff of cosmic rays, lower energy particles will be recorded and monitored. According to numerical simulations, it is expected that solar cosmic rays, such as the so-called Ground Level Enhancements (GLEs), which are critical events in space weather, can be observed from these detectors at this new site of LAGO (Masías-Meza and Dasso, 2014).

Regarding ionospheric research, open questions still remain to be solved like the coupling between the neutral and ionized atmosphere, with the exploration of the different modes of waves and tides propagations in conjunction with several ionospheric measurements. Further steps to solve these puzzles have been taken by the Latin American group at INPE with the realization of the International SpreadFEx campaign (simultaneous observation of the mesosphere and ionosphere during the plasma bubble activities) carried out in 2005, with several important scientific results (Fritts et al., 2009). Planetary scale wave propagations, such as Rossby and Kelvin waves, were investigated using the photometer and ionosonde data. Presence of ultra-fast Kelvin wave (3.5 day oscillation) was found in the equatorial ionosphere (Takahashi et al., 2006).

More recently, another step to further investigate the neutral and ionized atmospheres with more temporal and spatial resolution has been taken in Brazil with the establishment of the Embrace/INPE Space Weather Program. Under the auspice of this program the Brazilian airglow group took responsibility to set up an airglow-monitoring site at geomagnetic conjugate points, Boa Vista (RR, 2.9° N, 60.7° W) and Campo Grande (MT, 20.5° S, 54.5° W). This was done to monitor the plasma bubble events over the conjugate points at a permanent base.

Also, as mentioned above, the recently formed ionospheric group at the UNIVAP is publishing several articles to help fulfill the knowledge regarding the response of equatorial and low latitude ionospheric regions to solar variability (de Jesus et al., 2011; Bolzan et al., 2013), solar flares (Raulin et al., 2010) and geomagnetic storms (Sahai et al., 2007; Fagundes et al., 2008; Abalde et al., 2009; de Jesus et al., 2010; de Abreu et al., 2011; Sahai et al., 2012; de Jesus et al., 2013). In addition, several studies about the coupling between the lower stratosphere and the upper troposphere have been developed by groups in the Department of Atmospheric Sciences and the Oceans (DCAO) at UBA, in Argentina, such as studies of the displacement of the total Ozone and the Antarctic vortex, which can occur up to about 55° S (e.g., Vigliarolo et al., 2005). The background acquired from such studies present opportunities to obtain new developments in the near future in this branch of space weather.

4. Summary and conclusions

We presented a (limited) historical perspective of the space science development in Latin America, highlighting the most significant results and scientific contributions in the solar, the interplanetary medium, the magnetosphere and geomagnetic field, the neutral and ionized Earth's atmosphere research, including the development of solar–terrestrial interactions models. We began from the development of the first research in the early 1960s up to the most recent studies, coming to the current status of the space research in Latin America, and pointing notable scientific challenges in space weather.

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

AEB	Brazilian Space Agency, from the Portuguese Agência Espacial Brasileira
AEM	Mexican Space Agency, from the Spanish Agencia Espacial Mexicana
ALAGE	Latin American Space Geophysics Association, from the Spanish Asociación Latino Americana de Geofísica Espacial
CASLEO	Astronomical Complex "el Leoncito", from the Spanish Complejo AStronómico el LEOncito
CIASUR	Center for Upper Atmosphere and Radio propagation Research, from the Spanish Centro de Investigación de Atmósfera Superior y Radio propagación
CLTC	China's Launch, Tracking and Control Center
CNEA	National Atomic Energy Commission, from the Spanish Comisión Nacional de Energía Atómica
CNES	National Center for Space Studies, from the French Centre National d'Etudes Spatiales
CNRC	National Center of Cosmic Radiation, from the Spanish Centro Nacional de Radiación Cósmica
CONAE	National Commission on Space Research, from the Spanish Comisión Nacional de Actividades Espaciales
CONEE	Commission for the Outer Space, from the Spanish Comisión Nacional del Espacio Exterior
CONICET	National Council of Scientific and Technical Research, from the Spanish Consejo Nacional de Investigaciones Científicas y Técnicas
CONICET/ICATE	Institute of Astronomical Sciences, Earth and Space, from the Spanish Instituto de Ciencias Astronómicas, de la Tierra y del Espacio
COSPAR	Committee on Space Research
CRAAM	Center of Radio Astronomy and Astrophysics, Mackenzie, from the Portuguese Centro de Rádio Astronomia e Astrofísica, Mackenzie
CSEM	Center for Space Environment Modeling
CTA	Technical Center of Aeronautics, from the Portuguese Centro Técnico Aeroespacial
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
GOCNAE	National Commission Organization Group of Space Activities, from the Portuguese Grupo de Organização da Comissão Nacional de Atividades Espaciais
GRAPE	GNSS Research and Application for Polar Environment group
HAWC	High Altitude Water Cherekov Gamma Ray Observatory
IAA	Argentine Antarctic Institute, from the Spanish Instituto Antártico Argentino
IAFE	Institute of Astronomy and Space Physics, from the Spanish Instituto de Astronomía y Física del Espacio
IAG	Institute of Astronomy, Geophysics and Atmospheric Sciences, from the Portuguese Instituto de Astronomia, Geofísica e Ciências Atmosféricas
IATE	Institute for Theoretical and Experimental Astronomy, from the Spanish Instituto de Astronomía Teórico y Experimental

IGF/UNAM	Institute of Geophysics at UNAM, from the Spanish Instituto de Geofísica de la Universidad Nacional Autónoma de México
ILWS	International Living With a Star program
INGV	National Institute of Geophysics and Volcanology
INPE	National Institute for Space Research, from the Portuguese Instituto Nacional de Pesquisas Espaciais
ISWI	International Space Weather Initiative
LAGO	Latin American Giant Observatory
MAGHEL	MAGnetosphere and HELiosphere group
MCTI	Ministry of Science Technology and Innovations, from the Portuguese Ministério de Ciência Tecnologia e Inovação
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
OAFA	Félix Aguilar Astronomical Observatory, from the Spanish Observatorio Astronómico Félix Aguilar
PUIDE	University Program of Space Research and Development, from the Spanish Programa Universitario de Investigación y Desarrollo Espacial
ROI	Itapetinga Radio Observatory, from the Portuguese Rádio Observatório de Itapetinga
SCAR	Scientific Committee on Antarctic Research
SCiESMEX	Mexican Space Weather Service, from the Spanish Servicio de Clima Espacial, México
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
UNC	National University of Córdoba, from the Spanish Universidad Nacional de Córdoba
UNESP	Paulista State University, from the Portuguese Universidade Estadual Paulista "Júlio de Mesquita Filho"
UNIVAP	University of the Paraiba Valley, from the Portuguese Universidade do Vale do Paraíba
UNLP	National University of La Plata, from the Spanish Universidad Nacional de La Plata
UNT	National University of Tucumán, from the Spanish Universidad Nacional de Tucumán
URSI	International Union of Radio Science, from the French Union Radio Scientifique Internationale
USP	São Paulo University, from Portuguese Universidade de São Paulo
UTN	National Technological University, from the Spanish Universidad Tecnológica Nacional

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

AIS	Advanced Ionospheric Sounder
BATS-R-US	Block Adaptive Tree Solar wind-Roe-Upwind Scheme model
BDA	Brazilian Decimetric Array
CCD	Charge-Coupled Device
CORSIKA	COsmic Ray SImulations for KAscade model
DSA3	Deep Space Antennae
GNSS	Global Navigation Satellite Systems
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GUMICS-4	Grand Unified Magnetosphere-Ionosphere Coupling Simulation model
HASTA	H-Alpha Solar Telescope for Argentina
ICARE	Influence of Space Radiation on Advanced Components payload, from Spanish Influencia en los Componentes Avanzados de la Radiación Espacial
IGRF	International Geomagnetic Reference Field model
IRI	International Reference Ionosphere model
LFM	Lyon-Fedder-Mobarry model
MEXART	Mexican Array Radiotelescope
MICA	Mirror Coronagraph for Argentina
OPenGGCM	Open General Circulation Model
PPMLR	Piecewise Parabolic Method with a Lagrangian Remap model

RAPEAS	Argentine Network for the Study of the Upper Atmosphere, from the Spanish Red Argentina para el Estudio de la Alta Atmósfera
SAC	Scientific Applications Satellite, from the Spanish Satélite de Aplicaciones Científicas
SST	Solar Submillimeter Telescope
SUPIM	Sheffield University Plasmasphere-Ionosphere Model
SWMF	Space Weather Modeling Framework model

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

3D	three-dimensional
AR(s)	Active Region(s)
CME(s)	Coronal Mass Ejection(s)
CR(s)	Cosmic Ray(s)
EEJ	Equatorial Electrojet
GIC(s)	Ground Induced Current(s)
GLE(s)	Ground Level Enhancement(s)
GW(s)	Gravity Wave(s)
HF	High Frequency
HILDCAA(s)	High Intensity Long Duration Continuous Auroral Activity(s)
ICME(s)	Interplanetary Coronal Mass Ejection(s)
IMF	Interplanetary Magnetic Field
MC(s)	Magnetic Cloud(s)
MHD	Magneto-Hydro-Dynamic
SAMA	South American Magnetic Anomaly
TEC	Total Electron Content
TID(s)	Travelling Ionospheric Disturbance(s)
TR(s)	Transition Region(s)
ULF	Ultra-Low Frequency
VHF	Very High Frequency

References

Abalde, J.R., Sahai, Y., Fagundes, P.R., Becker-Guedes, F., Bittencourt, J.A., Pillat, V.G., Lima, W.L.C., Candido, C.M.N., de Freitas, T.F., 2009. Day-to-day variability in the development of plasma bubbles associated with geomagnetic disturbances. J. Geophys. Res.: Space Phys. 114. http://dx.doi.org/10.1029/2008JA013788 A04304.

Abdu, M.A., Batista, I.S., 1977. Sporadic E-layer phenomenon in the Brazilian Geomagnetic Anomaly: evidence for a regular particle ionization source. J. Atmos. Solar Terr. Phys. 39 (6), 723–732.

Abdu, M.A., Bittencourt, J.A., Batista, I.S., 1981. Magnetic declination control of the equatorial F region dynamo field development and spread F. J. Geophys. Res. 86, 11443–11446.

Abdu, M.A., Jayahandran, P.T., MacDougall, J., Cecile, J.F., Sobral, J.H.A., 1998. Equatorial F region zonal plasma irregularity drifts under magnetospheric disturbances. Geophys. Res. Lett. 25 (22), 4137–4140.

Abdu, M.A., Batista, I.S., Carrasco, A.J., Brum, C.G.M., 2005. South Atlantic magnetic anomaly ionization: a review and a new focus on electrodynamic effects in the equatorial ionosphere. J. Atmos. Solar Terr. Phys. 67, 1633–1657.

Abdu, M.A., Batista, P.P., Batista, I.S., Brum, C.G.M., Carrasco, A., Reinisch, B.W., 2006. Planetary wave oscillations in mesospheric winds, equatorial evening pre-reversal electric field and spread F. Geophys. Res. Lett. 33 (L07107). http://dx.doi.org/10.1029/2005GL024837.

Abdu, M.A., de Paula, E.R., Batista, I.S., Reinisch, B.W., Matsuoka, M. T., Camargo, P.O., Veliz, O., Denardini, C.M., Sobral, J.H.A., KheraniSantos, E.A., 2008. Abnormal evening vertical plasma drift and effects on ESF and EIA over Brazil-South Atlantic sector during the 30 October 2003 superstorm. J. Geophys. Res. 113, A07313. http://dx.doi.org/10.1029/2007JA012844.

Abdu, M.A., Kherani, E.A., Batista, I.S., Batista, P.P., Paula, E.R., de Paula Fritts, D., Sobral, J.H.A., 2009. Gravity wave initiation of equatorial spread F/plasma bubble irregularities based on observational data from the SpreadFEx campaign. Ann. Geophys. Ser. A, Upper Atmosphere and Space Sciences 27, 2607–2622.

Abdu, M.A., Brum, C.G.M., Batista, P.P., Gurubaran, S., Pancheva, D., Bageston, J.V., Batista, I.S., Takahashi, H., 2015. Fast and ultra-fast Kelvin wave modulations of the equatorial evening F region vertical drift and spread F development. Earth Planets Space 67 (1). http://dx.doi.org/10.1186/s40623-0140143-5.

Abreu, P., Aglietta, M., Ahn, E.J., et al., 2011. The Pierre Auger Observatory scaler mode for the study of solar activity modulation of galactic cosmic rays. J. Instrum. 6, P01003. http://dx.doi.org/10.1088/1748-0221/6/01/P01003. (FERMILAB-PUB-11-037-AD-AE-CD-TD).

Aguilar-Rodriguez, E., Gopalswamy, N., MacDowall, R., Yashiro, S., Kaiser, M.L., 2005. A universal characteristic of type II radio bursts. J. Geophys. Res.: Space Phys. 110 (A12S08). http://dx.doi.org/10.1029/2005JA011171.

Aguilar-Rodriguez, E., Blanco-Cano, X., Russell, C.T., Luhmann, J.G., Jian, L.K., Ramírez Vélez, J.C., 2011. Dual observations of interplanetary shocks associated with stream interaction regions. J. Geophys. Res. 116 (A12). http://dx.doi.org/10.1029/2011JA016559.

Andrés, N., Gómez, D., Bertucci, C., Mazelle, C., Dougherty, M.K., 2013. Saturn ULF wave foreshock boundary: Cassini observations. Planet. Space Sci. 79, 64–75.

Andrés, N., Gonzalez, C., Martin, L., Dmitruk, P., Gómez, D., 2014. Two-fluid turbulence including electron inertia. Phys. Plasmas 21, 122305. http://dx.doi.org/10.1063/1.4903907.

Asorey, H., Dasso, S., Núñez, L.A., Peréz, Y., Sarmiento-Cano, C., Suárez-Durán, M.for The LAGO Collaboration, 2015. The LAGO space weather program: directional geomagnetic effects, background fluence calculations and multi-spectral data analysis. Proceeding of Science, PoS (ICRC2015), vol. 142. Available online: <http://pos.sissa.it/archive/conferences/236/142/ICRC2015_142.pdf>.

Attrill, G., Nakwacki, M.S., Harra, L.H., van Driel-Gesztelyi, L., Mandrini, C.H., Dasso, S., Wang, J., 2006. Using the evolution of coronal dimming regions to probe the global magnetic field topology. Sol. Phys. 238, 117–139.

Aveiro, H.C., Denardini, C.M., Abdu, M.A., 2009a. Climatology of gravity waves induced electric fields in the equatorial E region. J. Geophys. Res. 114. http://dx.doi.org/10.1029/2009JA0.

Aveiro, H.C., Denardini, C.M., Abdu, M.A., 2009b. Signatures of 2-day wave in the E-region electric fields and their relationship to winds and ionospheric currents. Ann. Geophys. 27, 631–638.

Azpilicueta, F., Brunini, C., 2012. A different interpretation of the annual and semiannual anomalies on the magnetic activity over the Earth. J. Geophys. Res.: Space Phys. 117, A08202. http://dx.doi.org/10.1029/2012JA017893.

Bagala, L.G., Bauer, O.H., Fernandez Borda, R., Francile, C., Haerendel, G., Rieger, R., Rovira, M.G., 1999. The new Ha solar telescope at the german-argentinian solar observatory. In: Wilson, A. et al. (Eds.), Magnetic Fields and Solar Processes, ESA Special Publication, vol. 448, pp. 469–474.

Bagala, L.G., Stenborg, G., Schwenn, R., Haerendel, G., 2001. The eruptive events on September 30, 1998: 1. The jet. J. Geophys. Res. 106, 25239–25248.

Bailey, G.J., Balan, N., 1996. A low-latitude ionosphere–plasmasphere model. In: Schunk, R.W. (Ed.), Step Handbook on Ionospheric Models. Utah State University, Logan, Utah, pp. 173–206.

Bailey, G.J., Sellek, R., 1990. A mathematical model of the Earth's plasmasphere and its application in a study of He^+ at $L = 3$. Ann. Geophys. 8, 171–190.

Bailey, G.J., Sellek, R., Rippeth, Y., 1993. A Modelling study of the equatorial topside ionosphere. Ann. Geophys. 11, 263–272.

Bailey, G.J., Su, Y.Z., Balan, N., 1997. The Sheffield university plasmasphere ionosphere model - A review. J. Atmos. Solar Terr. Phys. 59, 1541–1552.

Balmaceda, L., Dal Lago, A., Stenborg, G., Francile, C., Gonzalez, W.D., Schwenn, R., 2003. Continuous tracking of CMEs using MICA, and LASCO C2 and C3 coronagraphs. Adv. Space Res. 32, 2625–2630.

Balogh, A., González-Esparza, J.A., Forsyth, R.J., Burton, M.E., Goldstein, B.E., Smith, E.J., Bame, S.J., 1995. Interplanetary shock waves: ULYSSES observations in and out of the ecliptic. Planet Space Sci. Rev. 72 (1–2), 171–180.

Batista, I.S., Abdu, M.A., 1977. Magnetic storm associated delayed sporadic-E enhancement in the Brazilian Geomagnetic Anomaly. J. Geophys. Res. 82 (29), 4777–4783.

Batista, I.S., Abdu, M.A., 2004. Ionospheric variability at Brazilian low and equatorial latitudes: comparison between observations and IRI model. Adv. Space Res. 34, 1894–1900.

Batista, I.S., Abdu, M.A., Bittencourt, J.A., 1986. Equatorial F region vertical plasma drifts: seasonal and longitudinal asymmetries in the American sector. J. Geophys. Res. 91, 12055–12064.

Batista, P.P., Takahashi, H., Gobbi, D., Medeiros, A.F., 2000. First airglow all sky images at 23 S. Adv. Space Res. 26, 925–928.

Bertucci, C., Achilleos, N., Dougherty, M.K., Modolo, R., Coates, A.J., Szego, K., Masters, A., Ma, Y., Neubauer, F.M., Garnier, P., Wahlund, J.-E., Young, D.T., 2008. The magnetic memory of Titan's ionized atmosphere. Science 321 (5895), 1475–1478. http://dx.doi.org/10.1126/science.1159780.

Blanco-Cano, X., Schwartz, S.J., 1997. Identification of low-frequency kinetic wave modes in the Earth's ion foreshock. Ann. Geophys. 15 (3), 273–288.

Blanco-Cano, X., Omidi, N., Russell, C.T., 2006. Macrostructure of collisionless bow shocks: 2. ULF waves in the foreshock and magnetosheath. J. Geophys. Res.: Space Phys. 111 (A10205). http://dx.doi.org/10.1029/2005JA011421.

Blanco-Cano, X., Omidi, N., Russell, C.T., 2009. Global hybrid simulations: foreshock waves and cavitons under radial interplanetary magnetic field geometry. J. Geophys. Res. 114 (A01216). http://dx.doi.org/10.1029/2008JA013406.

Bolzan, M.J.A., Tardelli, A., Pillat, V.G., Fagundes, P.R., Rosa, R.R., 2013. Multifractal analysis of vertical total electron content (VTEC) at equatorial region and low latitude, during low solar activity. Ann. Geophys. 31 (1), 127–133. http://dx.doi.org/10.5194/angeo-31-127-2013.

Borgazzi, A., Costa, A., 2005. Characterization of intensity and spatial variations along coronal loops. II. A TRACE case study. Astron. Astrophys. 441, 327–335.

Bravo, S., 1995. A solar scenario for the associated occurrence of flares, eruptive prominences, coronal mass ejections, coronal holes, and interplanetary shocks. Sol. Phys. 161 (1), 57–65.

Bravo, S., González-Esparza, J.A., 2000. The north–south asymmetry of the solar and heliospheric magnetic field during activity minima. Geophys. Res. Lett. 27 (6), 847–849.

Bravo, S., Otaola, J.A., 1989. Polar coronal holes and the sunspot cycle – A new method to predict sunspot numbers. Sol. Phys., 0038-0938 122 (2), 335–343.

Bravo, S., Stewart, G.A., 1995. The inclination of the heliomagnetic equator and the presence of an inclined relic field in the Sun. Astrophys. J. 446, 431–434.

Bravo, S., Stewart, G.A., 1997. Fast and slow wind from solar coronal holes. Astrophys. J. 489 (2), 992–999.

Bravo, S., Stewart, G.A., Blanco-Cano, X., 1998. The varying multipolar structure of the Sun's magnetic field and the evolution of the solar magnetosphere through the solar cycle. Sol. Phys. 179 (2), 223–235. http://dx.doi.org/10.1023/A:1005017329287.

Brunini, C., Meza, A., Azpilicueta, F., van Zele, M.A., Gende, M., Días, A., 2004. A new ionosphere monitoring technology based on GPS. Astrophys. Space Sci. 290, 415–429.

Caballero, R., Valdés-Galicia, J.F., 2001. Galactic cosmic ray fluctuations during solar cycles 22 and 23 at high altitude neutron monitors. Adv. Space Res. 27 (3), 583–588.

Cantó, J., González, R.F., Raga, A.C., De Gouveia Dal Pino, E.M., Lara, A., González-Esparza, J.A., 2005. The dynamics of velocity fluctuations in the solar wind – I. Coronal mass ejections, 2005. Mon. Not. R. Astron. Soc. 357 (2), 572–578.

Cardoso, F.R., 2006. Simulação MHD bi-dimensional da interação do vento solar com magnetosferas planetárias (in English: Two-dimensional MHD simulation of the solar wind interaction with planetary magnetospheres. 92 p. (inpe-14643-tdi/1203)) (MSc dissertation) Space Geophysics. Instituto Nacional de Pesquisas Espaciais, São José dos Campos. Available online: <http://urlib.net/sid.inpe.br>.

Cardoso, F.R., Gonzalez, W.D., Sibeck, D.G., Kuznetsova, M., Koga, D., 2013. Magnetopause reconnection and interlinked flux tubes. Ann. Geophys. 31 (10), 1853–1866. http://dx.doi.org/10.5194/angeo-31-1853-2013.

Carrillo-Vargas, A., Pérez-Enríquez, R., Rodríguez-Martínez, M., López-Montes, R., Casillas-Pérez, G.A., Araujo-Pradere, E.A., 2012. Ionospheric disturbances detected by mexart. Adv. Space Res. 49 (11), 1570–1580.

Cécere, M., Schneiter, M., Costa, A., Elaskar, S., Maglione, S., 2012. Simulation of descending multiple supra-arcade reconnection outflows in solar flares. Astrophys. J. 759 (79). http://dx.doi.org/10.1088/0004-637x/759/2/79.

Chian, A.C.-L., Miranda, R.A., Rempel, E.L., Saiki, Y., Yamada, M., 2010. Amplitude–phase synchronization at the onset of permanent spatiotemporal chaos. Phys. Rev. Lett. 104, 254102. http://dx.doi.org/10.1103/PhysRevLett. 104.254102.

Cid, C., Cremades, H., Aran, A., Mandrini, C., Sanahuja, B., Schmieder, B., Menvielle, M., Rodriguez, L., Saiz, E., Cerrato, Y., Dasso, S., Jacobs, C., Lathuillere, C., Zhukov, A., 2012. Can a halo CME from the limb be geoeffective?. J. Geophys. Res: Space Phys. 117 (A16) A11102. http://dx.doi.org/10.1029/2012JA017536.

Clúa-Gonzalez, A.L., Gonzalez, W.D., Dutra, S.L.G., Tsurutani, B.T., 1993. Periodic variation in the geomagnetic activity: a study based on the Ap index. J. Geophys. Res. 98 (A6), 9215–9231. http://dx.doi.org/10.1029/92JA02200.

Corona-Romero, P., González-Esparza, J.A., 2011. Numeric and analytic study of interplanetary coronal mass ejection and shock evolution: driving, decoupling, and decaying. J. Geophys. Res. 116 (A05104). http://dx.doi.org/10.1029/2010JA016008.

Corona-Romero, P., González-Esparza, J.A., Aguilar-Rodriguez, E., De-la-Luz, V., Mejia-Ambriz, J.C., 2015. Kinematics of ICMEs/Shocks: blast wave reconstruction using Type-II emissions. Sol. Phys. 290, 2439–2454. http://dx.doi.org/10.1007/s11207-015-0683-2.

Costa, A., Stenborg, G., 2004. Characterization of intensity variations along Fe XIV coronal loops – A case study. Sol. Phys. 222, 229–245. http://dx.doi.org/10.1023/B:SOLA.0000043570.97010.b7.

Cremades, H., Mandrini, C.H., Dasso, S., 2011. Coronal transient events during two solar minima: their solar source regions and interplanetary counterparts. Sol. Phys. 274, 233–249. http://dx.doi.org/10.1007/s11207-011-9769-7.

Cremades, H., Iglesias, F.A., St. Cyr, O.C., Xie, H., Kaiser, M.L., Gopalswamy, N., 2015. Low-frequency type II radio detections and coronagraph data to describe and forecast the propagation of 71 CMEs/shocks. Sol. Phys. 290, 2455–2478. http://dx.doi.org/10.1007/s11207-015-0776-y.

Cristiani, G., Martínez, G., Mandrini, C.H., Giménez de Castro, C.G., Rovira, M.G., Kaufmann, P., Levato, H., 2005. Submillimeter-wave and Ha observations of the event on 28 November 2001. J. Atmos. Solar Terr. Phys. 67, 1744–1750. http://dx.doi.org/10.1016/j.jastp.2005.02.025.

Cristiani, G., Martínez, G., Mandrini, C.H., Giménez de Castro, C.G., da Silva, C.W., Rovira, M.G., Kaufmann, P., 2007. Spatial characterization of a flare using radio observations and magnetic field topology. Sol. Phys. 240, 271–281. http://dx.doi.org/10.1007/s11207-006-0337-5.

Cristiani, G., Giménez de Castro, C.G., Mandrini, C.H., Machado, M.E., Silva, I.D.B.E., Kaufmann, P., Rovira, 2008. A solar burst with a spectral component observed only above 100 GHz during an M class flare. Astron. Astrophys. 492, 215–222. http://dx.doi.org/10.1051/0004-6361:200810367.

Dal Lago, A., Vieira, L.E.A., Echer, E., Gonzalez, W.D., Clua-Gonzalez, A.L., Guarnieri, F.L., Schuch, N.J., Schwenn, R., 2004. Comparison between halo CME expansion speeds observed on the sun, related shock transit speeds to Earth and corresponding ejecta speeds at 1 au. Sol. Phys. 222 (2), 323–328.

Dasso, S., Gómez, D., Mandrini, C.H., 2002. Ring current decay rates of magnetic storms: a statistical study from 1957 to 1998. J. Geophys. Res. 107 (A5), 1059. http://dx.doi.org/10.1029/2000JA000430.

Dasso, S., Mandrini, C.H., DéMoulin, P., Farrugia, C.J., 2003. Magnetic helicity analysis of an interplanetary twisted flux tube. J. Geophys. Res. 108 (A10), 1362. http://dx.doi.org/10.1029/2003JA009942.

Dasso, S., Mandrini, C.H., Démoulin, P., Luoni, M.L., Gulisano, A., 2005a. Large scale MHD properties of interplanetary magnetic clouds. Adv. Space Res. 35 (5), 711–724.

Dasso, S., Milano, L.J., Matthaeus, W.H., Smith, C.W., 2005b. Anisotropy in fast and slow solar wind fluctuations. Astrophys. J. 635, l181–l184.

Dasso, S., Mandrini, C.H., Démoulin, P., Luoni, M.L., 2006. A new model-independent method to compute magnetic helicity in magnetic clouds. Astron. Astrophys. 455 (1), 349–359.

Dasso, S., Nakwacki, M.S., Démoulin, P., Mandrini, C.H., 2007. Progressive transformation of a flux rope to an ICME. Sol. Phys. 244 (1–2), 115–137. http://dx.doi.org/10.1007/s11207-007-9034-2.

Dasso, S., Mandrini, C.H., Schmieder, B., Cremades, H., Cid, C., Cerrato, Y., Saiz, E., Démoulin, P., Zhukov, A.N., Rodriguez, L., Aran, A., Menvielle, M., Poedts, S., 2009. Linking two consecutive nonmerging magnetic clouds with their solar sources. J. Geophys. Res. 114 (A2), A02109.

Dasso, S., Demoulin, P., Gulisano, A.M., 2012a. Magnetic clouds along the solar cycle: expansion and magnetic helicity, in Comparative Magnetic Minima: characterizing quiet times in the Sun and stars. In: Mandrini, C.H., Webb, D.F. (Eds.), Proceedings IAU Symposium, vol. 286. Proceedings of the International Astronomical Union, Paris, pp. 139–148. http://dx.doi.org/10.1017/S1743921312004759.

Dasso, S., Asorey, H. for the Pierre Auger Collaboration, 2012b. The scaler mode in the Pierre Auger Observatory to study heliospheric modulation of cosmic rays. Adv. Space Res. 49 (11), 1563–1569.

Dasso, S., Gulisano, A.M., Masías-Meza, J.J., Asorey, H.for the LAGO collaboration, 2015. A project to install water-cherenkov detectors in the Antarctic Peninsula. In: Dasso, H. (Ed.), Proceeding of Science, PoS (ICRC2015), vol. 105. Available online: <http://pos.sissa.it/archive/conferences/236/105/ICRC2015_105.pdf>.

de Abreu, A.J., Sahai, Y., Fagundes, P.R., de Jesus, R., Bittencourt, J.A., Pillat, V.G., 2011. An investigation of ionospheric F region response in the Brazilian sector to the super geomagnetic storm of May 2005. Adv. Space Res. 48 (7), 1211–1220. http://dx.doi.org/10.1016/j.asr.2011.05.036.

de Abreu, A.J., Fagundes, P.R., Gende, M., Bolaji, O.S., de Jesus, R., Brunini, C., 2014. Investigation of ionospheric response to two moderate geomagnetic storms using GPS-TEC measurements in the South American and African sectors during the ascending phase of solar cycle 24. Adv. Space Res. 53, 1313–1328.

de Jesus, R., Sahai, Y., Guarnieri, F.L., Fagundes, P.R., de Abreu, A.J., Becker-Guedes, F., Brunini, C., Gende, M., Cintra, T.M.F., de Souza, V.A., Pillat, V.G., Lima, W.L.C., 2010. Effects observed in the ionospheric F-region in the South American sector during the intense geomagnetic storm of 14 December 2006. Adv. Space Res. 46 (7), 909–920. http://dx.doi.org/10.1016/j.asr.2010.04.031.

de Jesus, R., Sahai, Y., Guarnieri, F.L., Fagundes, P.R., de Abreu, A.J., Pillat, V.G., Lima, W.L.C., 2011. F-region ionospheric parameters observed in the equatorial and low latitude regions during medium solar activity in the Brazilian sector and comparison with the IRI-2007 model results. Adv. Space Res. 47 (4), 718–728. http://dx.doi.org/10.1016/j.asr.2010.10.020.

de Jesus, R., Sahai, Y., Fagundes, P.R., de Abreu, A.J., Brunini, C., Gende, M., Bittencourt, J.A., Abalde, J.R., Pillat, V.G., 2013. Response of equatorial, low- and mid-latitude F-region in the American sector during the intense geomagnetic storm on 24–25 October 2011. Adv. Space Res. 52 (1), 147–157. http://dx.doi.org/10.1016/j.asr.2013.03.017.

de Mendonça, F., 1965. Ionospheric electron content measurements in regions of low magnetic dip and through the Brazilian Magnetic Anomaly, Space Research V. In: Proceedings of the Fifth Int. Space Science Symposium, Florence, May 12–16. North Holland, Amsterdam, pp. 687–701.

Demoulin, P., Dasso, S., 2009a. Causes and consequences of magnetic cloud expansion. Astron. Astrophys. 498, 551–566.

Demoulin, P., Dasso, S., 2009b. Magnetic cloud models with bent and oblate cross-section boundaries. Astron. Astrophys. 507, 969–980.

Denardini, C.M., Abdu, M.A., Sobral, J.H.A., Janardhanan, K.V., Vasudevanpillai, M.S., 1999. VHF ionospheric radar for studying the electrodynamics of the equatorial electrojet in Brazil. Revista Geofísica, México, D.F., México 50, 151–161.

Denardini, C.M., Abdu, M.A., Sobral, J.H.A., 2003. Detection of three distinct regions in the equatorial electrojet in the Brazilian sector. Braz. Geophys. J. 21 (1), 65–74.

Denardini, C.M., Abdu, M.A., Sobral, J.H.A., 2004. VHF radar studies of the equatorial electrojet 3-m irregularities over São Luís: day-to-day variabilities under auroral activity and quiet conditions. J. Atmos. Solar Terr. Phys. 66 (17), 1603–1613.

Denardini, C.M., Abdu, M.A., De Paula, E.R., Sobral, J.H.A., Wrasse, C.M., 2005. Seasonal characterization of the equatorial electrojet height rise over Brazil as observed by the RESCO 50 MHz back-scatter radar. J. Atmos. Solar Terr. Phys. 67, 1665–1673.

Denardini, C.M., Abdu, M.A., de Paula, E.R., Wrasse, C.M., Sobral, J.H.A., 2006. VHF radar observations of the dip equatorial E-region during sunset in the Brazilian sector. Ann. Geophys. 24 (1–7), 1617–1623.

Denardini, C.M., Abdu, M.A., Aveiro, H.C., Resende, L.C.A., Almeida, P.D.S.C., Olívio, Ê.P.A., Sobral, J.H.A., Wrasse, C.M., 2009. Counter electrojet features in the Brazilian sector: simultaneous observation by radar, digital sounder and magnetometers. Ann. Geophys. 27, 1593–1603.

Denardini, C.M., Aveiro, H.C., Almeida, P.D.S.C., Resende, L.C.A., Guizelli, L.M., Moro, J., Sobral, J.H.A., Abdu, M.A., 2011. Daytime efficiency of different time scale prompt penetration electric fields to equatorial latitudes. J. Atmos. Solar Terr. Phys. 73, 1555–1559.

Denardini, C.M., Moro, J., Resende, L.C.A., Chen, S.S., Schuch, N.J., Costa, J.E.R., 2015. E region electric field dependence of the solar activity. J. Geophys. Res.: Space Phys. 120. http://dx.doi.org/10.1002/2015JA021714.

Denardini, C.M., Dasso, S., Gonzalez-Esparza, J.A., 2016. Review on space weather in Latin America. 2. The research networks ready for space weather. Adv. Space Res. 58 (10), 1940–1959.

Domingues, M.O., Gomes, A.K.F., Gomes, S.M., Mendes Jr., O.M., Pierro, B., Schneider, K., 2013. Extended generalized Lagrangian multipliers for magnetohydrodynamics using adaptive multiresolution methods. ESAIM Proceedings, vol. 43, pp. 95–107.

Echer, E., Gonzalez, W.D., Tsurutani, B.T., 2008. Interplanetary conditions leading to superintense geomagnetic storms ($Dst < -250$ nt) during solar cycle 23. Geophys. Res. Lett. 35 (6), L06S03. http://dx.doi.org/10.1029/2007GL031755.

Elias, L.A.R., Berbert, C.O., Janot, E., Bica, E.L.D., Oliveira Fl, K.S., Barbuy, B.L.S., Novello, M., Miranda, O.D., Bruch, A.J.R., Silva, D. F., deLaReza, J.R., 2010. Plano Nacional de Astronomia (in English: National Plan for Astronomy). Available online: <http://www.sab-astro.org.br/CEA>.

Fagundes, P.R., Muella, M.T.A.H., Bittencourt, J.A., Sahai, Y., Lima, W. L.C., Guarnieri, F.L., Becker-Guedes, F., Pillat, V.G., Ferreira, A.S., Lima, N.S., 2008. Nighttime ionosphere-thermo sphere coupling observed during an intense geomagnetic storm. Adv. Space Res. 41 (4), 539–547. http://dx.doi.org/10.1016/j.asr.2007.11.005.

Fernandez Borda, R.A., Mininni, P.D., Mandrini, C.H., Gómez, D.O., Bauer, O.H., Rovira, M.G., 2002. Automatic solar flare detection using neural network techniques. Sol. Phys. 206, 347–357. http://dx.doi.org/10.1023/A:1015043621346.

Forbush, S.E., 1938. On cosmic ray effects associated with magnetic storms. J. Terr. Magnet. Atmos. Electricity 43, 203–218. http://dx.doi.org/10.1029/TE043i003p00203.

Forbush, S.E., 1957. Solar influences on cosmic rays. Proc. Natl. Acad. Sci. U.S.A. 43 (1), 28–41. http://dx.doi.org/10.1073/pnas.43.1.28.

Forbush, S.E., Gill, P.S., Vallarta, M.S., 1949. On the mechanism of sudden increase of cosmic radiation associated to solar flare. Rev. Mod. Phys. 21, 44–48.

Francile, C., Costa, A., Luoni, M.L., Elaakar, S., 2013. Hα moreton waves observed on December 06, 2006. A 2D case study. Astron. Astrophys. 552 (A3). http://dx.doi.org/10.1051/0004-6361/201118001.

Fraser-Smith, A.C., 1987. Centered and eccentric geomagnetic dipoles and their poles, 1600–1985. Rev. Geophys. 25, 1–16. http://dx.doi.org/10.1029/RG025i001p00001.

Fritts, D.C., Abdu, M.A., Batista, B.R., Batista, I.S., Batista, P.P., Buriti, R., Clemesha, B.R., Dautermann, T., de Paula, E.R., Fechine, B.J., Fejer, B.G., Gobbi, D., Haase, J., Kamalabadi, F., Kherani, E.A., Laughman, B., Lima, P.P., Liu, H.-L., Medeiros, A., Pautet, P.-D., Riggin, D.M., Rodrigues, F.S., São Sabbas, F., Sobral, J.H.A., Stamus, P., Takahashi, H., Taylor, M.J., Vadas, S.L., Vargas, F., Wrasse, C.M., 2009. Overview and summary of the Spread F experiment (SpreadFEx). Ann. Geophys. 27, 2141–2155. http://dx.doi.org/10.5194/angeo-27-2141-2009.

Gall, R., 1987. Latin American space activities based on different infrastructures. Adv. Space Res. 7 (3), 123–127.

Gall, R., Jimenez, J., Camacho, L., 1968. Arrival of low-energy cosmic rays via the magnetospheric tail. J. Geophys. Res. 73, 1593–1605.

Gall, R., Orozco, A., Marin, C., Hurtado, A., Vidargas, G., 1982. Tables of approach directions and points of entry of cosmic rays for high latitude cosmic ray station. The Institute of Geophysics of UNAM, Mexico, p. 421p.

Gall-Sonabend, O., 2000. Ruth Gall, Ciencia y Tecnología en el México en el siglo XXI, Biografias de Personajes Ilustres, México, Academia Mexicana de Ciencias, Consejo Consultivo de Ciencias de la Presidencia de La República (in English: Ruth Gall, Science and Technology in Mexico in the XXI century, Biographies of famous people, Mexico, Mexican Academy of Sciences, Science Advisory Council of the Presidency of the Republic), vol. IV. CONACYT.

Gianibelli, J.C., Quaglino, N., 2007. Efecto de las variaciones magnéticas de origen Antártico sobre un gasoducto en Tierra del Fuego (in English: Effect of magnetic variations of Antarctic origin on a pipeline at Tierra del Fuego). In: VI Simposio Argentino y III LatinoAmericano sobre investigaciones Antárticas, Buenos Aires, 10–13. Available online: <http://www.dna.gov.ar/ciencia/santar07/cd/pdf/cfqre202.pdf>.

Gianibelli, J.C., García, R.E., Solans, J.H., Cabassi, I.R., Quaglino, N., 2008. El observatorio magnetico digital de Las Acacias y su utilidad en la industria petrolera (in English: The digital magnetic observatory of Las Acacias and its usefulness in the oil industry). In: Actas XVII Congreso Geologico Argentino, (6–10 October 2008). San Salvador de JuJy, ISBN 978-987-22403-1-8, pp. 1093–1094.

Giménez de Castro, C.G., Cristiani, G.D., Simoes, P.J.A., Mandrini, C. H., Correia, E., Kaufmann, P., 2013. A Burst with double radio spectrum observed up to 212 GHz. Sol. Phys. 284, 541–558. http://dx.doi.org/10.1007/s11207-012-0173-8.

Gombosi, T.I., De Zeeuw, D.L., Groth, C.P.T., Powell, K.G., Stout, Q.F., 2000. Multiscale MHD simulation of a coronal mass ejection and its interaction with the magnetosphere–ionosphere system. J. Atmos. Solar Terr. Phys. 62 (16), 1515–1525. http://dx.doi.org/10.1016/S1364-6826(00)00091-2.

Gombosi, T.I., Dezeeuw, D.L., Groth, C.P.T., et al., 2001. From Sun to Earth multiscale MHD simulations of space weather. In: Song, P., Singer, H.J., Siscoe, G.L. (Eds.), Geophysical Monograph Series, vol. 125. American Geophysical Union, Washington, DC, ISBN 0-87590-984-1, pp. 169–176.

Gómez, D.O., Dmitruk, P., 2008. Turbulent heating of coronal active regions. In: Erdelyi, R., Mendoza-Briceno, C.A. (Eds.), Proc. IAU Symp. 247: Waves and Oscillations in the Solar Atmosphere, pp. 269–278.

Gómez, D.O., Ferro-Fontán, C., 1988. Coronal heating by selective decay of MHD turbulence. Sol. Phys. 116, 33–44.

Gonzalez, W.D., Burch, J.L., 2012. Key Processes in Solar-Terrestrial Physics. Springer, NY, ISBN: 9781461414926, 166 p.

Gonzalez, W.D., Mozer, F.S., 1974. A quantitative model for the potential resulting from reconnection with an arbitrary interplanetary magnetic field. J. Geophys. Res. 79 (28), 4186–4194.

Gonzalez, W.D., Parker, E.N., 2016. Magnetic Reconnection: Concepts and Applications. Springer, N.Y., ISBN 978-3-319-26430-1.

Gonzalez, W.D., Dutra, S.L.G., Pinto Jr., O., 1987. Middle atmospheric-electrodynamic modification by particle precipitation at the SAMA. J. Atmos. Solar Terr. Phys. 49 (4), 377–383. http://dx.doi.org/10.1016/0021-9169(87)90032-8.

Gonzalez, W.D., Joselyn, J.A., Kamide, Y., Kroehl, H.W., Rostoker, G., Tsurutani, B.T., Vasyliunas, V.M., 1994. What is a geomagnetic storm? J. Geophys. Res. 99 (4), 5771–5792.

Gonzalez, W.D., Guarnieri, F.L., Gonzalez, A.L.C., Echer, E., Alves, M. V., Ogino, T., Tsurutani, B.T., 2006. Magnetospheric energetics during HILDCAAs. In: Tsurutani, B.T. et al. (Eds.), Recurrent Magnetic Storms: Corotating SolarWind Streams, Geophysical Monograph Series, vol. 167. AGU, Washington, D.C, pp. 175–182.

Gonzalez, W.D., Echer, E., Clua-Gonzalez, A.L., Tsurutani, B.T., 2007. Interplanetary origin of intense geomagnetic storms (Dst<-100 nt). Geophys. Res. Lett. 34, L06101. http://dx.doi.org/10.1029/2006GL028879.

Gonzalez, W.D., Echer, E., Tsurutani, B.T., Clua-Gonzalez, A.L., Dal Lago, A., 2011. Interplanetary origin of intense, superintense and extreme geomagnetic storms. Space Sci. Rev. 158, 69–89.

González-Esparza, J.A., Balogh, A., Forsyth, R.J., Neugebauer, M., Smith, E.J., Phillips, J.L., 1996. Interplanetary shock waves and large-scale structures: Ulysses' observations in and out of the ecliptic plane. J. Geophys. Res. 101 (A8), 17057–17072.

González-Esparza, J. Américo, Lara, Alejandro, Pérez-Tijerina, Eduardo, Santillán, Alfredo, Gopalswamy, N., 2003. A numerical study on the acceleration and transit time of coronal mass ejections in the interplanetary medium. J. Geophys. Res.: Space Phys. 108 (A1). http://dx.doi.org/10.1029/2001JA009186, CiteID 1039, pp. SSH 9-1.

González-Esparza, J.A., Carrillo, A., Andrade, E., Perez, R., Kurtz, S., 2004. The MEXART interplanetary scintillation array in Mexico. Geofís. Int. 43 (1), 61–73.

Gopalswamy, N., Lara, A., Lepping, R.P., Kaiser, M.L., Berdichevsky, D., St. Cyr, O.C., 2000. Interplanetary acceleration of coronal mass ejections. Geophys. Res. Lett. 27 (2), 145–148.

Gopalswamy, N., Lara, A., Yashiro, Seiji, Nunes, S., Howard, R.A., 2003. Coronal mass ejection activity during solar cycle 23. In: Wilson, A. (Ed.), Solar variability as an input to the Earth's environment. International Solar Cycle Studies (ISCS) Symposium, 23–28 June 2003, Tatranská Lomnica, Slovak Republic. ESA Publications Division, ESA SP-535, Noordwijk, ISBN 92-9092-845-X, pp. 403–414.

Guizelli, L.M., Denardini, C.M., Moro, J., Resende, L.C.A., 2013. Climatological study of the daytime occurrence of the 3-meter EEJ plasma irregularities over Jicamarca close to the solar minimum (2007 and 2008). Earth, Planets and Space 65, 39–44.

Gulisano, A., Démoulin, P., Dasso, S., Ruiz, M.E., Marsch, E., 2010. Global and local expansion of magnetic clouds in the inner heliosphere. Astron. Astrophys. 509 (26). http://dx.doi.org/10.1051/0004-6361/200912375 A39.

Heck, D., Knapp, J., Capdevielle, J.N., Schatz, G., Thouw, T., 1998. CORSIKA: a Monte Carlo code to simulate extensive air showers, Forschungszentrum Karlsruhe GmbH, Karlsruhe, TIB Hannover, D-30167 Hannover.

Janhunen, P., Palmroth, M., Laitinen, T., Honkonen, I., Juusola, L., Facskó, G., Pulkkinen, T.I., 2012. The GUMICS-4 global MHD magnetosphere-ionosphere coupling simulation. J. Atmos. Solar Terr. Phys. 80, 48–59. http://dx.doi.org/10.1016/j.jastp.2012.03.006.

Janvier, M., Dasso, S., Demoulin, P., Masías-Meza, J.J., Lugaz, N., 2015. Best generic model for interplanetary shocks and magnetic clouds axis at 1 AU. J. Geophys. Res. 120, 3328–3349. http://dx.doi.org/10.1002/2014JA020836.

Jauer, P.R., 2010. Simulação magneto-hidrodinâmcia da resposta da magnetocauda da terra ás variações do campo magnético interplanetário (in English: MHD simulation of the Earth magnetotail response to variations of the interplanetary magnetic field. 103 p. (sid.inpe.br/mtc-m19@80/2010/02.03.11.28-tdi)) (MSc dissertation) Space Geophysics. São José dos Campos, Brasil. Available online: <http://urlib.net/8jmkd3mgp7w/36smqns>.

Jauer, P.R., 2014. Estudo sobre reconexão magnética na magnetopausa terrestre por meio de simulação MHD 3D BATS-R-US (in English: Study of magnetic reconnection in the Earth's magnetopause through MHD simulation 3D using BATS-R-US. 181 p. (sid.inpe.br/mtc-m21b/2014/04.17.16.08-TDI)) (PhD thesis) Space Geophysics. São José dos Campos, Brasil. Available online: <http://urlib.net/8JMKD3MGP5W34M/3G66A85>.

Kajdic, P., Blanco-Cano, X., Omidi, N., Russell, C.T., 2011. Multi-spacecraft study of foreshock cavitonsupstream of the quasi-parallel bow shock. Planet. Space Sci. 59 (8), 705–714.

Kherani, E.A., Abdu, M.A., de Paula, E.R., Fritts, D., Sobral, J.H.A., de Meneses Jr, F.C., 2009. The impact of gravity waves rising from convection in the lower atmosphere on the generation and nonlinear evolution of equatorial bubble. Ann. Geophys. Ser. A, Upper Atmosphere and Space Sciences 27, 1657–1668.

Klausner, V., Fagundes, P.R., Sahai, Y., Wrasse, C.M., Pillat, V.G., Becker-Guedes, F., 2009. Observations of GW/TID oscillations in the F2 layer at low latitude during high and low solar activity, geomagnetic quiet and disturbed periods. J. Geophys. Res.: Space Phys. 114 (A02313). http://dx.doi.org/10.1029/2008JA013448.

Koga, D., Gonzalez, W.D., Mozer, F., Silveira, M.V.D., Cardoso, F.R., 2014. Larmor electric field observed at the Earth's magnetopause by polar satellite. Phys. Plasmas 21. http://dx.doi.org/10.1063/1.4897935 100701.

Lanavere, V., Dasso, S., Masías-Mesa, J.J., Gulisano, A.M., 2015. Caracterización de los efectos sobre Argentina de un evento extremo de Meteorología Espacial (in English: Characterization of the effects of an extreme Space Weather event over Argentina). In: Presentation at the XII Congreso Argentino de Meteorología (CONGREMET XII), Mar del Plata, Argentina, 26-29 May.

Lange, I., Forbush, S.E., 1948. Cosmic-Ray Results from Huancayo Observatory, Peru, June 1936-December, 1946. Including summaries from Observatories at Cheltenham, Christchurch, and Godhavn through 1946. In: Tuve, M.A., Fleming, J.A. (Eds.), Researches of the Department of the Terrestrial Magnetism Volume XIV. Carnegie Institutions of Washington Publications, Washington, D.C., 182 p.

Lara, A., 2008. The source region of coronal mass ejections. Astrophys. J. 688 (1), 647–655.

Lara, A., Gopalswamy, N., Nunes, S., Muñoz, G., Yashiro, S., 2003. A statistical study of CMEs associated with metric type II bursts. Geophys. Res. Lett. 30 (12). http://dx.doi.org/10.1029/2002GL01648, CiteID 8016.

Lara, A., Gopalswamy, N., Caballero-López, R.A., Yashiro, S., Xie, H., Valdés-Galicia, J.F., 2005. Coronal mass ejections and galactic cosmic-ray modulation. Astrophys. J. 625 (1), 441–450.

Leboeuf, J.N., Tajima, T., Kennel, C.F., Dawson, J.M., 1978. Global simulation of the time-dependent magnetosphere. Geophys. Res. Lett. 5 (7), 609–612.

Loesch, C., Opher, M., Alves, M.V., Evans, R.M., Manchester, W.B., 2011. Signatures of two distinct driving mechanisms in the evolution of coronal mass ejections in the lower corona. J. Geophys. Res. 116, A04106. http://dx.doi.org/10.1029/2010JA015582.

López-Montes, R., Pérez-Enríquez, R., Araujo-Pradere, E.A., 2012. The impact of large solar events on the total electron content of the ionosphere at mid latitudes. Adv. Space Res. 49 (7), 1167–1179.

Luoni, M.L., Mandrini, C.H., Dasso, S., van Driel-Gesztelyi, L., Demoulin, P., 2005. Tracing magnetic helicity from the solar corona to the interplanetary space. J. Atmos. Solar Terr. Phys. 67, 1734–1743. http://dx.doi.org/10.1016/j.jastp.2005.07.003.

Luoni, M.L., Mandrini, C.H., Cristiani, G.D., Demoulin, P., 2007. The magnetic field topology associated with two M flares. Adv. Space Res. 39, 1382–1388. http://dx.doi.org/10.1016/j.asr.2007.02.005.

Lyon, J.G., Brecht, S.H., Huba, J.D., Fedder, J.A., Computer, Palmadesso P.J., 1981. Simulation of a geomagnetic substorm. Phys. Rev. Lett. 46 (15), 1038–1041.

Lyon, J.G., Fedder, J.A., Mobarry, C.M., 2004. The Lyon–Fedder–Mobarry (LFM) global MHD magnetospheric simulation code. J. Atmos. Solar Terr. Phys. 66, 1333–1350.

Mandrini, C.H., Demoulin, P., van Driel-Gesztelyi, L., Green, L.M., Lopez Fuentes, M.C., 2004. Magnetic helicity budget of solar-active regions from the photosphere to magnetic clouds. Astrophys. Space Sci. 290, 319–344. http://dx.doi.org/10.1023/B:ASTR.0000032533.31817.0e.

Mandrini, C.H., Pohjolainen, S., Dasso, S., Green, L.M., Demoulin, P., van Driel-Gesztelyi, L., Copperwheat, C., Foley, C., 2005. Interplanetary flux rope ejected from an X-ray bright point. The smallest magnetic cloud source-region ever observed. Astron. Astrophys. 434, 725–740. http://dx.doi.org/10.1051/0004-6361:20041079.

Mandrini, C.H., Nakwacki, M.S., Attrill, G., van Driel-Gesztelyi, L., Demoulin, P., Dasso, S., Elliott, H., 2007. Are CME-related dimmings always a simple signature of interplanetary magnetic cloud footpoints? Solar Phys. 244, 25–43. http://dx.doi.org/10.1007/s11207-007-9020-8.

Mandrini, C.H., Schmieder, B., Demoulin, P., Guo, Y., Cristiani, G.D., 2014. Topological analysis of emerging bipole clusters producing violent solar events. Sol. Phys. 289, 2041–2071. http://dx.doi.org/10.1007/s11207-013-0458-6.

Maravilla, D., Lara, A., Valdés Galicia, J.F., Mendoza, B., 2001. An analysis of polar coronal hole evolution: relations to other solar phenomena and heliospheric consequences. Sol. Phys. 203 (1), 27–38.

Masías-Meza, J.J., Dasso, S., 2013. Galactic cosmic ray decreases associated with non-interacting magnetic clouds in the 23rd solar cycle. In: Schmieder, Brigitte, Malherbe, Jean-Marie, Wu, Shi T. (Eds.), Proc. of Nature of Prominences and their Role in Space Weather, IAU Symposium No. 300. Cambridge University Press, Cambridge, pp. 451–452. http://dx.doi.org/10.1017/S1743921313011654.

Masías-Meza, J.J., Dasso, S., 2014. Geomagnetic effects on cosmic ray propagation under different conditions for Buenos Aires and Marambio, Argentina. Sun Geosphere 9, 41–47.

Matsumoto, H., Omura, Y., 1993. Computer Space Plasma Physics: Simulation Techniques and Software. Terrapub, Tokyo, pp. 161–207. Available online: <https://www.terrapub.co.jp/e-library/cspp/>.

Medeiros, A.F., Taylor, M.J., Takahashi, H., Batista, P.P., Gobbi, D., 2001. An unusual airglow wave event observed at Cachoeira Paulista 23 degree S. Adv. Space Res. 27 (10), 1749–1754.

Medeiros, A.F., Buriti, R.A., Machado, E.A., Takahashi, H., Batista, P. P., Gobbi And M.J. Taylor,, D., Taylor, M.J., 2004. Comparison of gravity wave activity observed by airglow imaging from two different latitudes in Brazil. J. Atmos. Solar Terr. Phys. 60, 647–654. http://dx.doi.org/10.1016/j.jastp.2004.01.016.

Mendoza, E., 1995. Semblanza Manuel Sandoval Vallarta. Instituto Politécnico Nacional (IPN), Mexico.

Mendoza, B., Perez-Enriquez, R., 1993. Association of coronal mass ejections with the heliomagnetic current sheet. J. Geophys. Res. 98 (A6), 9365–9370.

Mendoza, B., Perez-Enriquez, R., 1995. Geoeffectiveness of the heliospheric current sheet. J. Geophys. Res. 100 (A5), 7877–7880.

Mininni, P., Gómez, D., Mindlin, B., 2001. Simple model of a stochastically excited solar dynamo. Sol. Phys. 201 (2), 203–223. http://dx.doi.org/10.1023/A:1017515709106.

Miroshnichenko, L.I., De Koning, C.A., Perez-Enriquez, R., 2000. Large solar event of September 29, 1989: ten years after. Space Sci. Rev. 91 (3/4), 615–715.

Morales, L.F., Dasso, S., Gómez, D.O., 2005. The Hall effect in incompressible magnetic reconnection. J. Geophys. Res. 110 (A04204). http://dx.doi.org/10.1029/2004JA010675.

Moro, J., Denardini, C.M., Abdu, M.A., Correia, E., Schuch, N.J., Makita, K., 2012a. Latitudinal dependence of cosmic noise absorption in the ionosphere over the SAMA region during the september 2008 magnetic storm. J. Geophys. Res. 117, A06311. http://dx.doi.org/10.1029/2011ja017405.

Moro, J., Denardini, C.M., Abdu, M.A., Correia, E., Schuch, N.J., Makita, K., 2013. Correlation between the cosmic noise absorption calculated from the SARINET data and the energetic particles measured by MEPED: simultaneous observations over SAMA region. Adv. Space Res. 51 (9), 1692–1700.

Mosert, M., Gende, M., Brunini, C., Ezquer, R., Altadill, D., 2007. Comparisons of IRI TEC predictions with GPS and digisonde measurements at Ebro. Adv. Space Res. 39 (5), 841–847.

Nakwacki, M.S., Dasso, S., Démoulin, P., Mandrini, C.H., Gulisano, A. M., 2011. Dynamical evolution of a magnetic cloud from the Sun to 5.4 AU. Astron. Astrophys. 535, 16. http://dx.doi.org/10.1051/0004-6361/201015853 A52.

Nogueira, P.A.B., Abdu, M.A., Souza, J.R., Batista, I.S., Bailey, G.J., Santos, A.M., Takahashi, H., 2013a. Equatorial ionization anomaly development as studied by GPS TEC and foF2 over Brazil: a comparison of observations with model results from SUPIM and IRI-2012. J. Atmos. Solar Terr. Phys. 104, 45–54.

Nogueira, P.A.B., Abdu, M.A., Souza, J.R., Bailey, G.J., Batista, I.S., Shume, E.B., Denardini, C.M., 2013b. Longitudinal variation in Global Navigation Satellite Systems TEC and topside ion density over South American sector associated with the four-peaked wave structures. J. Geophys. Res.: Space Phys. 118, 7940–7953.

Ogino, T., Walker, R.J., Ashour-Abdalla, M., Dawson, J.M., 1986. An MHD simulation of the effects of the interplanetary magnetic field By component on the interaction of the solar wind with the Earth's magnetosphere during southward interplanetary magnetic field. J. Geophys. Res. 91 (A9), 10029–10045. http://dx.doi.org/10.1029/JA091iA09p10029.

Ogino, T., Walker, R.J., Ashour-Abdalla, M., 1994. A global magnetohydrodynamic simulation of the response of the magnetosphere to a northward turning of the interplanetary magnetic field. J. Geophys. Res. 99, 11027–11042.

Ojeda, A., Gonzalez, W.D., Mendes, O., Domingues, M.O., Rosa, R.R., 2014. Nonlinear fluctuation analysis for a set of 41 magnetic clouds measured by the advanced composition explorer (ACE) spacecraft. Nonlinear Process. Geophys. (online) 21, 1059–1073.

Ontiveros, V., González-Esparza, J.A., 2010. Geomagnetic storms caused by shocks and ICMEs. J. Geophys. Res. 115 (A10244). http://dx.doi.org/10.1029/2010JA015471.

Ontiveros, V., Vourlidas, A., 2009. Quantitative measurements of coronal mass ejection-driven shocks from LASCO observations. Astrophys. J. 693 (1), 267–275.

Osella, A., Favetto, A., 2000. Effects of soil resistivity in buried pipelines. J. Appl. Geophys. 44, 303–312.

Osella, A., Martinelli, P., Favetto, A., López, E., 2002. Induction effects of 2D structures on buried pipelines. IEEE Geosci. Remote Sens. 40 (1), 197–205.

Otaola, J.A., Zenteno, G., 1983. On the existence of long-term periodicities in solar activity. Solar Phys., 0038-0938 89, 209–213.

Perez-de-Tejada, H., 1986. Fluid dynamic constraints of the Venus ionospheric flow. J. Geophys. Res., 0148-0227 91, 6765–6770.

Perez-de-Tejada, H., 1992. Solar wind erosion of the Mars early atmosphere. J. Geophys. Res., 0148-0227 97 (A3), 3159–3167.

Perez-de-Tejada, H., 1999. Viscous forces in velocity boundary layers around planetary ionospheres. Astrophys. J. 525 (1), L65–l68.

Perez-de-Tejada, H., Dryer, M., 1976. Viscous boundary layer for the Venusian ionopause. J. Geophys. Res. 81, 2023–2029.

Pérez-Enriquez, R., Miroshnichenko, L.I., 1999. Frequency distributions of solar gamma ray events related and not related with spes in 1980–1995. Sol. Phys. 188 (1), 169–185.

Perez-Peraza, J., 1986. Coronal transport of solar flare particles. Space Sci. Rev. 44, 91–138.

Perez-Peraza, J., 2009. Reminiscences of cosmic ray research in Mexico. Adv. Space Res. 44, 1215–1220. http://dx.doi.org/10.1016/j.asr.2008.11.031.

Perez-Peraza, J., Leyva, A., Libin, I., Formichev, V., Guschina, R.T., Yudakhin, K., Jaani, A., 1997. Simulating the mechanism of the action of heliophysical parameters on atmospheric processes. Geofis. Int. 36 (4), 245–280.

Pretz, J., for the HAWC collaboration, 2015. Highlights from the High Altitude Water Cherenkov Observatory – HAWC Collaboration. arXiv:1509.07851 [astro-ph.HE] HAWC-ICRC-2015-0866.

Prolss, G., 2004. Physics of the Earth's Space Environment: An Introduction. Springer, ISBN-13: 978-3540214267, 513 p.

Raeder, J., Larson, D., Li, W., Kepko, E.L., Fuller-Rowell, T., 2008. OpenGGCM simulations for the THEMIS mission. Space Sci. Rev. 141, 535–555. http://dx.doi.org/10.1007/s11214-008-9421-5.

Raulin, J.-P., Bertoni, F.C.P., Gavilán, H.R., Guevara-Day, W., Rodriguez, R., Fernandez, G., Correia, E., Kaufmann, P., Pacini, A.A., Stekel, Tardelli R.C., Lima, W.L.C., Schuch, N.J., Fagundes, P.R., Hadano, R., 2010. Solar flare detection sensitivity using the South America VLF network (SAVNET). J. Geophys. Res.: Space Phys. 115 (A7). http://dx.doi.org/10.1029/2009ja015154.

Resende, L.C.A., Denardini, C.M., 2012. Equatorial sporadic E-layer abnormal density enhancement during the recovery phase of the December 2006 magnetic storm: a case study. Earth, Planets and Space 64, 345–351.

Resende, L.C.A., Denardini, C.M., Batista, I.S., 2013. Abnormal fbEs enhancements in equatorial Es layers during magnetic storms of solar cycle 23. J. Atmos. Solar Terr. Phys. 102, 228–234.

Rodriguez, L., Zhukov, A.N., Dasso, S., Mandrini, C.H., Cremades, H., Cid, C., Cerrato, Y., Saiz, E., Aran, A., Menvielle, M., Poedts, S., Schmieder, B., 2008. Magnetic clouds seen at different locations in the heliosphere. Ann. Geophys., 0992-7689 26, 213–229.

Rodríguez-Martínez, M., Pérez-Enríquez, H.R., Carrillo-Vargas, A., López-Montes, R., Araujo-Pradere, E.A., Casillas-Pérez, G.A., Cruz-Abeyro, J.A.L., 2014. Ionospheric disturbances and their impact on IPS using MEXART observations. Sol. Phys. 289 (7), 2677–2695.

Roederer, J.G., 2003. Early cosmic-ray research in Argentina. Phys. Today 56 (1), 32–37. http://dx.doi.org/10.1063/1.1554134.

Roederer, J.G., Manzano, J.R., Santochi, O.R., Nerurkar, N., Troncoso, O., Palmeira, R.A.R., Schwachheim, G., 1961. Cosmic rays phenomena during the november 1960 solar disturbance. J. Geophys. Res. 66 (6), 1603–1610. http://dx.doi.org/10.1029/JZ066i006p01603.

Romanelli, N., Bertucci, C., Gómez, D., Mazelle, C., Delva, M., 2013. Proton cyclotron waves upstream from Mars: observations from Mars global surveyor. Planet. Space Sci. 76, 1–9. http://dx.doi.org/10.1016/j.pss.2012.10.011.

Rovero, A.C., 2009. Historia de la Astronomía de altas energías en Argentina (in English: History of High Energy Astronomy in Argentina). Asociación Argentina de Astronomía Book Series, vol. 2, pp. 357–402.

Ruffenach, A., Lavraud, B., Farrugia, C.J., Démoulin, P., Dasso, S., Owens, M.J., Sauvaud, J.-A., Rouillard, A.P., Lynnyk, A., Foullon, C., Savani, N.P., Luhmann, J.G., Galvin, A.B., 2015. Statistical study of magnetic cloud erosion by magnetic reconnection. J. Geophys. Res. 120. http://dx.doi.org/10.1002/2014JA020628.

Ruiz, M.E., Dasso, S., Matthaeus, W.H., Marsch, E., Weygand, J.M., 2011. Aging of anisotropy of solar wind magnetic fluctuations in the inner heliosphere. J. Geophys. Res. 116, A10102. http://dx.doi.org/10.1029/2011JA016697.

Ruiz, M.E., Dasso, S., Matthaeus, W.H., Weygand, M.J., 2014. Characterization of the turbulent magnetic integral length in the solar wind: from 0.3 to 5 astronomical units. Sol. Phys. 289, 3917–3933. http://dx.doi.org/10.1007/s11207-014-0531-9.

Sahai, Y., Becker-Guedes, F., Fagundes, P.R., Lima, W.L.C., Otsuka, Y., Huang, C.S., Espinoza, E.S., Pi, X., de Abreu, A.J., Bolzan, M.J.A., Pillat, V.G., Abalde, J.R., Pimenta, A.A., Bittencourt, J.A., 2007. Response of nighttime equatorial and low latitude F-region to the geomagnetic storm of August 18th, 2003, in the Brazilian sector. Adv. Space Res. 39 (8), 1325–1334. http://dx.doi.org/10.1016/j.asr.2007.02.064.

Sahai, Y., de Jesus, R., Fagundes, P.R., Selhorst, C.L., de Abreu, A.J., Ram, S.T., Aragon-Angel, A., Pillat, V.G., Abalde, J.R., Lima, W.L.C., Bittencourt, J.A., 2012. Effects observed in the equatorial and low latitude ionospheric F-region in the Brazilian sector during low solar activity geomagnetic storms and comparison with the COSMIC measurements. Adv. Space Res. 50 (10), 1344–1351. http://dx.doi.org/10.1016/j.asr.2012.07.006.

Santana, D.C., Sobral, J.H.A., Takahashi, H., Taylor, M.J., 2001. Optical studies of the ionospheric irregularities over the Brazilian region by nocturnal images of the OI630 nm emission. Adv. Space Res. 27 (6–7), 1207–1212.

Santos, P.M.T., Souza, J.R., Sobral, J.H.A., Bailey, G.J., Brum, C.G.M., 2005. Development of the Sheffield University Plasmasphere Ionosphere Model-enhanced (SUPIM-e). Presentation at the 2005 Cedar-GEM Joint Workshop, Santa Fe (USA).

Santos, P.M.T., 2005. Estudo da dinâmica do sistema ionosfera–termosfera por modelo teórico e observações experimentais (in English: Study of the dynamics of the ionosphere-thermosphere the system by theoretical model and experimental observations. (inpe-13270-tdi/1032)) (MSc dissertation) Space Geophysics. Instituto Nacional de Pesquisas Espaciais, São José dos Campos. Available online: <http://urlib.net/sid.inpe.br>.

Santos, A.M., Abdu, M.A., Sobral, J.H.A., Koga, D., Nogueira, P.A.B., Candido, C.M.N., 2012. Strong longitudinal difference in ionospheric responses over Fortaleza (Brazil) and Jicamarca (Peru) during the January 2005 magnetic storm, dominated by northward IMF. J. Geophys. Res. 117 (A08333). http://dx.doi.org/10.1029/2012JA017604.

Sasai, Y., Nagai, Y., Itow, Y., Matsubara, Y., Sako, T., Lopez, D., Itow, T., Munakata, K., Kato, C., Kozai, M., Miyazaki, T., Shibata, S., Oshima, A., Kojima, H., Tsuchiya, H., Watanabe, K., Koi, T., Valdés-Galicia, J.F., González, L.X., Ortiz, E., Musalem, O., Hurtado, A., Garcia, R., Anzorena, M., 2014. Performance of the SciBar Cosmic Ray Telescope (SciCRT) toward the detection of high energy solar neutrons in Solar Cycle 24, Earth. Planets Space 66, 130. http://dx.doi.org/10.1186/1880-5981-66-130.

Schrijver, C.J., Kauristie, K., Aylward, A.D., Denardini, C.M., Gibson, S.E., Glover, A., Gopalswamy, N., Grande, M., Hapgood, M., Heynderickx, D., Jakowski, N., Kalegaev, V.V., Lapenta, G., Linker, J.A., Liu, S., Mandrini, C.H., Mann, I.R., Nagatsuma, T., Nandy, D., Obara, T., O'Brien, T.P., Onsager, T., Opgenoorth, H.J., Terkildsen, M., Valladares, C.E., Vilmer, N., 2015. Understanding space weather to shield society: a global road map for 2015–2025 commissioned by COSPAR and ILWS. Adv. Space Res. 55 (12), 2745–2807. http://dx.doi.org/10.1016/j.asr.2015.03.023.

Selhorst, C.L., Silva, A.V.R., Costa, J.E.R., 2005. Solar atmospheric model with spicules applied to radio observation. Astron. Astrophys. 433 (1), 365–374. http://dx.doi.org/10.1051/0004-6361:20042043.

SEPLAN – Secretaria de Planejamento (1982). Avaliação e Perspectivas 1. Astronômia. CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico). Ciências Exatas e da Terra (in English: Evaluation and Prospects 1. Astronomy. CNPq (National Council for Scientific and Technological Development). Exact and Earth Sciences). Available online: <http://www.sab-astro.org.br/CEA>.

Shume, E.B., Denardini, C.M., De Paula, E.R., Trivedi, N.B., 2010. Variabilities of the equatorial electrojet in Brazil and Perú. J. Geophys. Res. 115. http://dx.doi.org/10.1029/2009JA0.

Shume, E.B., De Paula, E.R., Kherani, E.A., Abdu, M.A., Denardini, C.M., 2011. Equatorial electrojet plasma irregularities observed during late afternoon by the 30 MHz coherent scatter radar in São Luís, Brazil. J. Atmos. Solar Terr. Phys. 73, 1560–1567.

Sierra, F.P., Vazquez, S.H., Andrade, E., Mendoza, B., Rodriguez-Osorio, D., 2014. Development of a schumann-resonance station in Mexico: preliminary measurements. IEEE Antennas Propag. Mag. 56 (3), 112–119. http://dx.doi.org/10.1109/MAP.2014.6867687.

Silva, A.V.R., Laganá, T.F., Gimenez-Castro, C.G., Kaufmann, P., Costa, J.E.R., Levato, H., Rovira, M., 2005. Diffuse component spectra of solar active regions at submillimeter wavelengths. Sol. Phys. 227 (2), 265–281. http://dx.doi.org/10.1007/s11207-005-2787-6.

Silva, M.R., Gonzalez, W.D., Echer, E., Dal Lago, A., Vieira, L.E.A., Guarnieri, F.L., Lucas, A., de Schuch, N.J., Munakata, K., 2007. Multitaper spectral analysis of cosmic rays São Martinho da Serra's muon telescope and newark's neutron monitor data. Braz. Geophys. J. 25, 175–179.

Smart, D.F., Shea, M.A., Gall, R., 1969. The daily variation of trajectory-derived high-latitude cutoff rigidities in a model magnetosphere. J. Geophys. Res. 74 (19), 4731–4738. http://dx.doi.org/10.1029/ja074i019p04731.

Sobral, J.H.A., Abdu, M.A., Batista, I.S., 1980a. Airglow studies on ionosphere dynamics over low latitude in Brazil. Ann. Geophys. 36 (2), 199–204.

Sobral, J.H.A., Abdu, M.A., Batista, I.S., Zamlutti, C.J., 1980b. Association between plasma bubble irregularities and airglow disturbances over Brazilian low latitudes. Geophys. Res. Lett. 11 (7), 980–982.

Sobral, J.H.A., Abdu, M.A., Zamlutti, C.J., Batista, I.S., 1981. Wave disturbances in the low latitude ionosphere and equatorial ionospheric plasma depletions. J. Geophys. Res. 86 (A3), 1374–1378.

Sobral, J.H.A., Abdu, M.A., Takahashi, H., Taylor, M.J., Paula, E.R.D., Zamlutti, C.J., Borba, G.L., 2002. A study of the ionospheric plasma bubbles climatology over Brazil, based on 22 years (1977–1998) of OI630 nm airglow observation. J. Atmos. Solar Terr. Phys. 64 (12–14), 1517–1524.

Souza, J.R., 1997. Modelagem ionosférica em baixas latitudes no Brasil (in English: Ionospheric modeling at low latitudes in Brazil. (INPE-6395-tdi/611)) (PhD thesis) Space Geophysics. Instituto Nacional de Pesquisas Espaciais, São José dos Campos. Available online: <http://urlib.net/sid.inpe.br>.

Souza, J.R., Abdu, M.A., Batista, I.S., Bailey, G.J., 2000. Determination of vertical plasma drift and meridional wind using the Sheffield University Plasmasphere Ionosphere model and ionospheric data at equatorial and low latitudes in Brazil: summer solar minimum and maximum conditions. J. Geophys. Res. 105, 12813–12821.

Souza, J.R., Brum, C.G.M., Abdu, M.A., Batista, I.S., Asevedo Junior, W.D., Bailey, G.J., Bittencourt, J.A., 2010. Parameterized regional ionospheric model and a comparison of its results with experimental data and IRI representations. Adv. Space Res. 46, 1032–1038.

Stenborg, G., Schwenn, R., Srivastava, N., Inhester, B., Podlipnik, B., Rovira, M., Francile, C., 1999. MICA: the mirror coronagraph for Argentina. Space Sci. Rev. 87, 307–310. http://dx.doi.org/10.1023/A:1005141727375.

Stenborg, G., Bagala, L.G., Bauer, O.H., Borda, R.F., Francile, C., Haerendel, G., Rovira, M.G., Schwenn, R., 2000. First combined observations in the German-Argentinean solar observatory: correlations in quiet and eruptive phenomena at the limb. J. Atmos. Solar Terr. Phys. 62, 1553–1559. http://dx.doi.org/10.1016/S1364-6826(00)00084-5.

Takahashi, H., Clemesha, B.R., Simonich, D.M., Melo, S.M.L., Teixeira, N.R., Eras, A., 1996. Rocket measurements of the equatorial airglow: Multifot 92 database. J. Atmos. Solar Terr. Phys. 58 (16), 1943–1961.

Takahashi, H., Lima, L.M., Wrasse, C.M., Abdu, M.A., Batista, I.S., Gobbi, D., Buriti, R.A., Batista, P.P., 2005. Evidence on 2–4 day oscillations of the equatorial ionosphere h'F and mesospheric airglow emissions. Geophys. Res. Lett. 32, L12102. http://dx.doi.org/10.1029/2004GL022318.

Takahashi, H., Wrasse, C.M., Pancheva, D., Abdu, M.A., Batista, I.S., Lima, L.M., Batista, P.P., Clemesha, B.R., Shiokawa, K., 2006. Signatures of 3–6 day planetary waves in the equatorial mesosphere and ionosphere. Ann. Geophys. 24, 3343–3350.

Takahashi, H., Abdu, M.A., Taylor, M.J., Pautet, P.-D., de Paula, E., Kherani, E.A., Medeiros, A.F., Wrasse, C.M., Batista, I.S., Sobral, J.H.A., Gobbi, D., Arruda, D., Paulino, I., Vadas, S., Fritts, D., 2010. Equatorial ionosphere bottom-type spread F observed by OI630.0 nm airglow imaging. Geophys. Res. Lett. 37, L03102. http://dx.doi.org/10.1029/2009GL041802.

Takakura, T., Nitta, N., Kaufmann, P., Costa, J.E.R., Degaonkar, S.S., Ohki, K., 1983. Sub-second pulsations simultaneously observed at microwaves and hard X rays in a solar burst. Nature 302, 317–319. http://dx.doi.org/10.1038/302317a0.

Tóth, G., Sokolov, Igor V., Gombosi, T.I., Chesney, D.R., Clauer, C.R., De Zeeuw, D.L., Hansen, K.C., Kane, K.J., Manchester, W.B., Oehmke, R.C., Powell, K.G., Ridley, A.J., Roussev, I.I., Stout, Q.F., Volberg, O., Wolf, R.A., Sazykin, S., Chan, A., Yu, B., Kóta, J., 2005. Space weather modeling framework: a new tool for the space science community. J. Geophys. Res. 110, A12226. http://dx.doi.org/10.1029/2005JA011126.

Tóth, G., van der Holst, B., Sokolov, I.V., De Zeeuw, D.L., Gombosi, T.I., Fang, F., Manchester, W.B., Meng, X., Najib, D., Powell, K.G., Stout, Q.F., Glocer, A., Ma, Y., Opher, M., 2012. Adaptive numerical algorithms in space weather modeling. J. Comput. Phys. 231 (3), 870–903. http://dx.doi.org/10.1016/j.jcp.2011.02.006.

Tsurutani, B.T., Gonzalez, W.D., 1987. The cause of high-intensity long-duration continuous AE activity (HILDCAAS): interplanetary Alfvén wave trains. Planet. Space Sci. 35, 405–410.

Tsurutani, B.T., Gonzalez, W.D., Kamide, Y., Arballo, J., 1997. Magnetic Storms, 1. ed. American Geophysical Union, Washington, p. 172p.

Tsurutani, B.T., Gonzalez, W.D., Lakhina, G.S., Alex, S., 2003. The extreme geomagnetic storm of september 1–2, 1859. J. Geophys. Res. 108 (A7), 1268. http://dx.doi.org/10.1029/2002JA009504.

Tsurutani, B.T., Gonzalez, W.D., Clua-Gonzalez, A.L., Guarnieri, F., Gopalswamy, N., Grande, M., Kamide, Y., Kasahara, Y., Lu, G., Mann, I., Mcpherron, R., Soraas, F., Vasyliunas, V.M., 2006. Corotating solar wind streams and recurrent geomagnetic activity: a review. J. Geophys. Res. 111 (A07S01). http://dx.doi.org/10.1029/2005JA011273.

Tsyganenko, N.A., 2002. A model of the near magnetosphere with a dawn-dusk asymmetry. J. Geophys. Res. 107 (A8). http://dx.doi.org/10.1029/2001JA000219, CiteID 1179.

Valdés-Galicia, J.F., 1992. Interplanetary magnetic field fluctuations and the propagation of cosmic rays. Geofís. Int. 31 (1), 29–40.

Valdés-Galicia, J.F., Velasco, V., 2008. Variations of mid-term periodicities in solar activity physical phenomena. Adv. Space Res. 41 (2), 297–305.

Valdés-Galicia, J.F., Pérez-Enríquez, R., Otaola, J.A., 1996. The cosmic-ray 1.68-year variation: a clue to understand the nature of the solar cycle? Sol. Phys. 167 (1–2), 409–417.

Valdés-Galicia, J.F., Muraki, Y., Tsujihara, H., Sako, T., Musalem, O., Hurtado, A., Gonzalez, L.X., Matsubara, Y., Watanabe, K., Hirano, N., 2004. An improved solar neutron telescope installed at a very high altitude in Mexico. Nucl. Instrum. Methods Phys. Res., Sect. A 535 (3), 656–664.

Vallarta, M.S., 1933. The interpretation of the azimuthal effect of cosmic radiation. Phys. Rev. 44 (1), 1–3.

Vallarta, M.S., 1937. Longitude effect of cosmic radiation and the position of the Earth's magnetic center. Nature 139, 24–25. http://dx.doi.org/10.1038/139024b0.

Vallarta, M.S., Graef, C., Kusaka, S., 1939. Galactic rotation and the intensity of cosmic rays at the geomagnetic equator. Phys. Rev. Lett. 55 (1), 1–5.

Vallarta, M.S., Gall, R., Lifshitz, J., 1958. Geomagnetic coordinates and cosmic radiation. Phys. Rev. Lett. 109, 1403–1404.

Vigliarolo, P., Vera, C., Diaz, S., 2005. Synoptic-scale variability and its relationship with ozone and Antarctic vortex displacements. Mon. Weather Rev. 133, 2374–2386.

Zhang, J.J., Wang, C., Tang, B.B., Li, H., 2013. Effect of the solar wind conditions on the ionospheric equivalent current systems. Ann. Geophys. 31, 489–501.