State of the art and challenges of the Argentine space weather laboratory (LAMP) in the Antarctic Peninsula

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Resumen / El proyecto del nuevo laboratorio de Meteorología del Espacio en la base Argentina Marambio de la Antártida incluyó el montaje de un control térmico automático en el interior de su sala principal, de una estación meteorológica, de un magnetómetro y de un detector de rayos cósmicos. Este laboratorio antártico es parte de un proyecto interdisciplinario en el que participan diferentes instituciones, entre las que se encuentran principalmente el Instituto de Astronomía y Física del Espacio IAFE (CONICET - UBA), el Instituto Antártico Argentino (IAA-DNA) y el Departamento de Ciencias de la Atmósfera y los Océanos (DCAO) de la Facultad de Ciencias Exactas y Naturales (FCEN) de la Universidad de Buenos Aires (UBA). Conocer la variabilidad de los flujos de rayos cósmicos a nivel del suelo es una de las claves para caracterizar las condiciones del clima espacial. Los eventos de Meteorología del Espacio severos pueden afectar las tecnologías modernas, como los sistemas de posicionamiento geográfico, comunicaciones por radiofrecuencia y daños en satélites, entre otros. Comprender el origen y transporte de los rayos cósmicos requiere conocimientos interdisciplinarios en física, en astronomía, en ciencias espaciales y en meteorología, ya que estas partículas energéticas de origen galáctico interactúan con el plasma y campo magnético interplanetario, el campo geomagnético y con las partículas de la atmósfera antes de llegar a la superficie de nuestro planeta. El laboratorio cuenta entre su instrumentación con un detector de rayos cósmicos de Radiación de Cherenkov en agua, llamado Neurus. Este detector de astropartículas también es parte del Observatorio LAGO (Latin American Giant Observatory o bien Observatorio Gigante Latinoamericano) constituyendo el detector más austral de este observatorio, en funcionamiento ininterrumpido desde marzo de 2019 cuando comenzó sus observaciones. LAGO es un derivado del observatorio Pierre Auger, con un concepto de desarrollo de detectores de rayos cósmicos por efecto Cherenkov en agua de bajo costo y tamaño reducido, constituidos por nodos descentralizados que abarcan desde México a la Antártida. El detector de partículas Neurus se construyó y desarrolló con características tecnológicas antárticas específicas en el laboratorio espacial del IAFE por el grupo LAMP (Laboratorio Argentino de Meteorología del esPacio), y permite monitorear en tiempo real el flujo de rayos cósmicos que llegan a la superficie de la Tierra, en altas latitudes en el hemisferio sur.

Abstract / The project involving a new laboratory of Space Weather at the Argentine Marambio base in Antarctica, required the assembly of an automatic thermal control for the interior of its main room, a meteorological station, a magnetometer, and a cosmic ray detector. This Antarctic laboratory is part of an interdisciplinary project involving different institutions, among which are mainly the Instituto de Astronomía y Física del Espacio, IAFE (CONICET–UBA), the Instituto Antártico Argentino (IAA-DNA) and the Departamento de Ciencias de la Atmósfera y los Océanos (DCAO) of the Facultad de Ciencias Exactas y Naturales (FCEyN) of the Universidad de Buenos Aires (UBA). Knowing the variability of cosmic rays fluxes at ground level is crucial to characterize the conditions of Space Weather. Severe Space Weather events can affect modern technologies, such as geo-positioning systems, radio-frequency communications, and damage satellites, among others. Understanding the origin and transport of cosmic rays requires interdisciplinary knowledge in physics, in astronomy, in space sciences and in meteorology, since these energetic particles of galactic origin interact with the interplanetary plasma and magnetic field, the geomagnetic field and with the particles of the atmosphere before reaching the surface of our planet. Part of the instrumentation contained in the laboratory include a cosmic rays detector, based in Water Cherenkov radiation, called Neurus. This astroparticle detector is also part of the LAGO Observatory (Latin American Giant Observatory) constituting the southernmost detector of them, in an uninterrupted operation since March 2019 when it started its observations. LAGO is a spin-off of the Pierre Auger observatory, with a concept of developing cosmic ray detectors by Cherenkov effect in water of low cost and reduced size, consisting of decentralized nodes that span from Mexico to Antarctica. The particle detector Neurus was constructed and developed with specific antarctic characteristics in the space laboratory of IAFE by the LAMP (Laboratorio Argentino de Meteorología del esPacio) team, and it allows for monitoring in real time the flux of cosmic rays that reaches the surface of the Earth, at high latitudes in the southern hemisphere.

Keywords / solar–terrestrial relations — astroparticle physics — instrumentation: detectors

1. Introduction

Space Weather (SWx) became in the last 50 years a cutting edge scientific discipline world wide and, in particular in latin america (Denardini et al., 2016a,b,c). SWx involves the understanding of the Sun-Earth relationship, monitoring the Sun conditions and the expected physical interactions of the solar wind and interplanetary transients on the Sun-Earth background system. It also involves the thermospheric, ionospheric and magnetospheric variability due to exogenous and external forcing (e.g., Dasso & Shea, 2020), These conditions can also affect technological instrumentation at ground level and in space, such as communication systems, geopositioning satellite constellations and power distribution grids (among others), that is the reason why the knowledge on SWx (in addition to scientific interest) is also important for our social infrastructure. A project to install a SWx laboratory at the Argentine Marambio Base, in Antarctica, was developed almost a decade ago (Dasso et al., 2015). The construction of the laboratory and deployment of its instruments was done during the last three antarctic campaigns during the Southern Hemispheric summers of 2017–2018, 2018–2019, and 2019–2020 (Dasso et al., 2019a). The present paper describes the current state of this laboratory. In sections 2 and 3 we will briefly describe some activities of our LAMP group (the operative ones are extensively described in Lanabere et al., 2020). Section 4 will describe the development and deployment of the recent Antarctic laboratory, which is at the Argentinean Marambio station in the Antarctic Peninsula. In Section 5 we will present the background previous characterization of the site (Masías-Meza & Dasso, 2014). Finally, in Section 6, we will present our work in progress, preliminary results, and next steps.

2. LAMP group

LAMP (acronym from spanish "Laboratorio Argentino de Metorología del esPacio") is an inter–institutional research Laboratory (DCAO FCEN–UBA, IAFE UBA–CONICET, and IAA–DNA) for Space Weather basic science studies, instrumentation development, characterization and, testing, Research to Operation and Operation to Research activities (Lanabere et al., 2018) as well as real-time monitoring of Space weather conditions. Related information regarding the group can be found in the web page: `http://spaceweather.at.fcen.uba.ar/2/lamp/`

LAMP-Newrus participated in the recent international WHPI (Whole Heliosphere and Planetary Interactions) campaign during Jan-Feb of 2020 accompanying NASA satellite Parker Solar Probe offering our ground level high latitude Observatory measurements. LAMP is full member of ISES (International Space Environment Service), and officially appointed as the Argentine Regional Warning Center (RWC). Regarding social impact of the research lines, LAMP participated in the recent implementation of the SWx information service to ICAO (International Civil Aviation Organization) for decision making (for example re-routing or cancellation of civil flights), from its participation as auditors of SWx global centers of the Inter-Programme Team on Space Weather Information, Systems and Services (IPT-SWeISS) of the WMO (World Meteorological Organisation). The group has also links with different institutions at national and international levels (Lanabere et al., 2020) and it performs weekly bulletins with the SWx conditions, a subscription alert service and a web page offering different daily SWx products `http://spaceweather.at.fcen.uba.ar/2/index.html`.

In addition to the science focus, LAMP performs human resources training and capacity building (see e.g., results published by one of our students, Coppola et al., 2016) during the development of the project.

3. Scientific Objectives of the Antarctic LAMP Laboratory

The main scientific aims of the Antarctic SWx LAMP laboratory include (1) the study of astroparticles as tracers of SWx in an interdisciplinary approach, (2) analysis of the modulation of galactic cosmic rays from solar wind and magnetosphere transient conditions, (3) studies of cascades (i.e., development of secondary particles) of atmospheric radiation at ground and flight level and connections with atmospheric physics, (4) the analysis of phenomena such as FDs (Forbush Decreases) which are significant reductions of the cosmic rays flux due to Interplanetary Coronal Mass Ejections or other interplanetary structures) and GLEs (Ground Level Enhancements) which are increases of radiation flux of solar origin, generally originated in huge solar flares.

More broadly, the transport of cosmic rays in the heliosphere, magnetic reconnection processes in the Magnetosphere and in general in the Sun-Earth system are also of major interest and strongly linked with the objectives of the activities of this Antarctic laboratory.

In summary, this project is expected to provide knowledge in space weather and improve the knowledge in basic science, combining with numerical simulations and the analysis of 'in-situ' measurements, from the advantage and unique opportunity of obtaining cosmic rays observations using a water Cherenkov detector (see next Section) at a high latitude site location.

4. Antarctic Space Weather Laboratory of the LAMP group

The instruments inside the laboratory include a meteorological station, a magnetometer prototype, a GPS station, a Cherenkov effect particle detector (named Neurus), among others. This astroparticle detector is also part of the LAGO Observatory (Latin American Giant Observatory) constituting its southernmost detector of them in an uninterrupted operation since March 2019 when it was set operational. LAGO is a spin-off of the Pierre Auger Observatory, with a concept of developing cosmic ray detectors by Cherenkov effect in water of low cost and reduced size, consisting of decentralized nodes that span from Mexico to Antarctica.

Figure 1: Symbolic ribbon cutting during the inauguration of the Space weather laboratory at Marambio Base on the Argentine Antarctic Day.

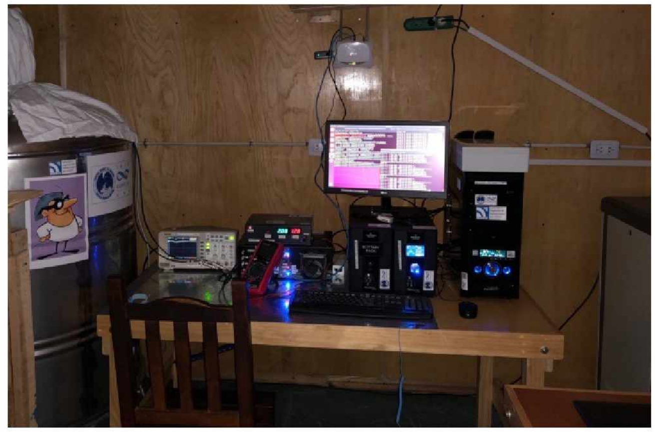

Figure 2: SWx LAMP Antarctic laboratory set up.

The LAMP Antarctic laboratory was inaugurated on February 22 on the Argentine Antarctic Day. The symbolic ribbon cutting of the facility is registered in the picture shown in Fig. 1. Installing a laboratory in Antarctic conditions and extreme climate implies a particular and specific design that had to be adapted to this defiant environment. In particular in the Marambio Base where the first Argentine Antarctic SWx laboratory was installed, this conditions implied adapting it to extreme temperatures that can reach -40 degrees Celsius (with thermal sensations that reach -60 degrees Celsius) and extreme winds with gusts between 100 and 300 $\mathrm{km\,h^{-1}}$. Among the particularities of the antarctic setting, it is worthwhile mentioning the following ones: separate electrical power lines for internal heating and lighting from those for data storage and backup equipment and systems. Three tons of scientific cargo were transported to the Antarctic Continent to set up the whole laboratory and the instrumentation inside in a challenging logistic maneuver. The aim was to ensure robustness, autonomous operation and data telemetry, as well as to comply with the environmental requirements of the Madrid protocol for Antarctic activities with the corresponding environmental impact study approval to ensure contamination prevention measurements minimizing impact. For the operation of the Cherenkov detector demineralized and distilled water was transported from the American Continent into the Marambio Base to avoid compromising the water resources of the station and to ensure the pure water needed for the correct operation of the detector. The demineralized water was also passed through an additional filtering system to improve performance. An acquisition system was developed to guarantee the redundancy, along with the design of self-made codes for storage and analysis of the data. To ensure autonomous operation under unscheduled power outage conditions, a special power bank system with gel battery redundancy was assembled and built with materials resistant to Antarctic conditions. A self-built meteorological station, calibrated at the SMN (*Servicio Meteorológico Nacional*) was developed and used. A GPS time stamp system with external output has been used for correct satellite reception, prepared to withstand extreme weather conditions in Antarctica, controlled by ARDUINO and with independent storage. There has been installed a thermal control system and a special isolation device (to obtain a signal outside the Faraday cage) that was designed by our group and previously tested in Marambio and that withstood winds and gusts as well as very low temperatures during the Antarctic winter. A redundant acquisition system was available to guarantee operability in different extreme conditions. A real-time transmission system for operational data was settled. A data storage and backup system for basic research purposes has also been implemented. The antenna support system for communication with the Internet system at the base was designed and installed with protection against prevailing winds and extreme temperatures. An alternate transmission system was made using a commercial sim-card in a modem. The laboratory has security measures such as fire extinguisher, smoke detector, internal communication line with the base and monitoring remote controlled web cameras, which can be accessed from internet and our group check from our laboratory in Buenos Aires at IAFE. The facility can be accessed safely through gateways if necessary. The project is led by Dr. Sergio Dasso and co-directed by Dr. Adriana María Gulisano. The current set up of the Laboratory at Marambio can be seen in Fig. 2.

4.1. Summer Campaign 2020 activities

During the summer Antarctic campaign of 2019–2020 a brand new faster acquisition system was implemented at the Marambio laboratory providing compatibility with other LAGO nodes. The two additional acquisition modes which were operating during the first year (2019) also continue in operations. A new in-house designed magnetometer was installed. An automatic thermalization system to maintain stable temperatures inside the laboratory was installed, preventing thermal drift in the electronics. Figure 3 shows the excellent performance of the thermal control. In the period rounded by a blue el-

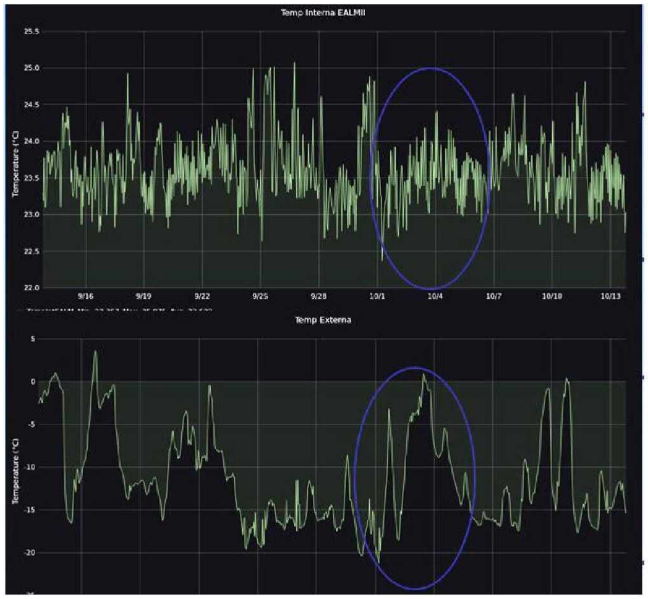

Figure 3: Temperature measurements in Celsius vs date during 2020. *Upper panel:* internal temperature at the laboratory. *Lower panel:* external temperature.

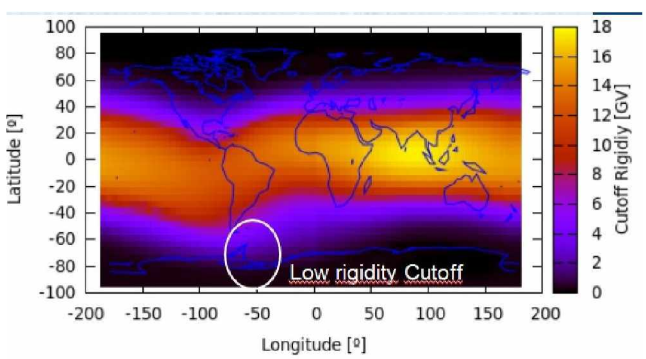

Figure 4: Rigidity cutoff as a function of latitude and longitude adapted from Masías-Meza & Dasso (2014).

lipse the external temperature suffer a strong variation of 20 Celsius while in the interior of the laboratory this variation was only 2 Celsius, maintaining the temperature in an optimal range between 24.5 and 22.5 Celsius. Two additional acquisition modes are being tested with different thresholds.

5. Site selection and characterization

In the context of this Antarctic project and for the proper characterization of the Marambio site, different studies were developed (e.g., Masías-Meza & Dasso, 2014; Dasso et al., 2015).

In order to study the flux of cosmic rays with compatible energies that allowed solar origin events to be measurable at the site, it is necessary to take into account the rigidity cutoff at different geomagnetic latitudes. The rigidity of a given particle is $R = cp/q$, with c the speed of light, q the particle electric charge, and p its linear moment. An effective rigidity can be computed for a given location, as can be seen in Fig. 4

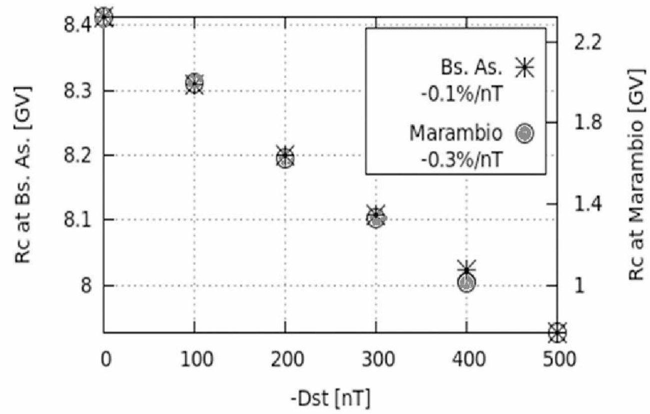

Figure 5: Rigidity cutoff as a function of the Dst index for the locations Marambio (blue circles) and Buenos Aires (asterisks), adapted from Masías-Meza & Dasso (2014).

Figure 6: Argentinean Antarctic Sector and the localization of Marambio Station indicated with a light blue arrow, permanent (all year) stations are indicated with green flags, while temporary (summer) stations are indicated with orange flags.

adapted from Masías-Meza & Dasso (2014). Moreover, as found in the previous study of Masías-Meza & Dasso (2014), the dependence of the rigidity cutoff (Rc) with the Dst index* was such that, for active geomagnetic activity, lower energetic particles could reach ground level, compared to the quiet conditions.

As can be observed in Fig. 5 (adapted from Masías-Meza & Dasso (2014)), a comparison between the rigidity at a mid latitude site (Buenos Aires) and a high

*The Dst index is a proxy frequently used to quantify the intensity of the so-called geomagnetic storms, which are strong geomagnetic disturbances and typically last around ten hours

Figure 7: Balloon launching at the Scientific Pavilion in Marambio Station (photo taken during the 2020 Summer campaign of LAMP researchers).

latitude one (Marambio) as a function of the Dst index reveals a linear decreasing rate of $\Delta Rc/\Delta Ds = -0.001$ GV nT^{-1} at Buenos Aires and $\Delta Rc/\Delta Ds = -0.003$ GV nT^{-1} at Marambio. For a Dst of 400 nT at the Antarctic station, the rigidity decreased to less than half the value for unperturbed conditions, while at mid-latitude the decrements were not considerable. Thus, the high latitude location was chosen as indicated in Fig. 6, where the site is marked with an arrow.

Additional characterizations were performed, since to analyze the cosmic flux of secondaries at ground level, the computation of the atmospheric differential depth is needed to make the Monte Carlo simulations of the cosmic rays cascades. Taking into account that the atmospheric depth at a certain height is the integral of the atmospheric density from infinite up to that height, then measurements of atmospheric profiles were analyzed.

The characterization of height atmospheric profiles of temperature and pressure in Marambio using balloon soundings data from 1998 up to 2014 were made. Balloon soundings are not an easy task to perform in Antarctica since the winds and low temperatures can affect the outcome and the cost is high. A launching at the scientific pavilion is illustrated at Fig. 7. In addition averages for each height level of GDAS (Global Data Assimilation System) data were considered. From pressure and temperature profiles we computed the density pro-

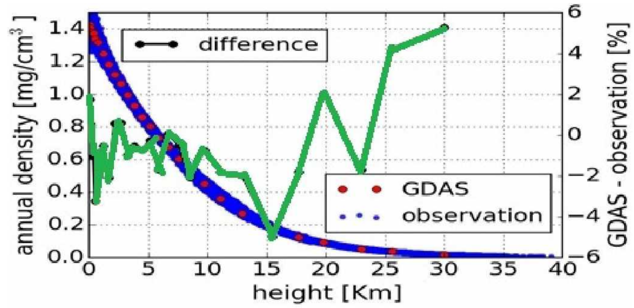

Figure 8: Comparison between density profiles obtained from observations and from GDAS as a function of height. Percent differences are displayed on the right axis, and annual densities on the left. Observations are plotted in blue, GDAS data in red, and percent differences in green.

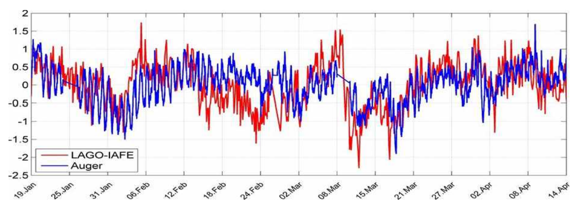

Figure 9: Relative percent comparison between low energy scalers of Pierre Auger observatory (blue line) and the cosmic flux rate measured at IAFE (red line) in 2015 during the FD period.

file using the standard atmosphere composition and the molecular weights. We compared these profiles with the MODTRAN atmosphere models usually used at CORSIKA simulations. The MODTRAN atmosphere profiles (Standard and Sub-Arctic) differed in the first ~ 7 km height at least in 10% (not shown), while the ones obtained from GDAS data modeled better the observed profile with percentage differences lower than $\sim 3\%$, as can be observed in Fig. 8. This result suggests using this approach to characterize other locations for astroparticle detectors since not always a 16 years of expensive balloon sounding data is available, so a very good option is the Global Data Assimilation System usage.

6. Firsts results and next steps

As mentioned in Sect. 3, interplanetary structures such as Interplanetary Coronal Mass Ejections (ICMEs) are able to prevent the diffusion of cosmic rays within the magnetic structure, which in turn translates into a decrease of cosmic rays observed at Earth; that phenomenon is called FD. There have been recent works analyzing the behaviour of cosmic rays relative fluxes observed at the Mac Murdo Antarctic Station during the passage of an ICME using a superposed epoch analysis (Masías-Meza et al., 2016).

The detector deployed in the LAMP Antarctic laboratory was in permanent operation in Buenos Aires during the previous assembling, testing and improvement stages. In that period the Cherenkov detector at Buenos Aires detected a FD on March 2015. The flux

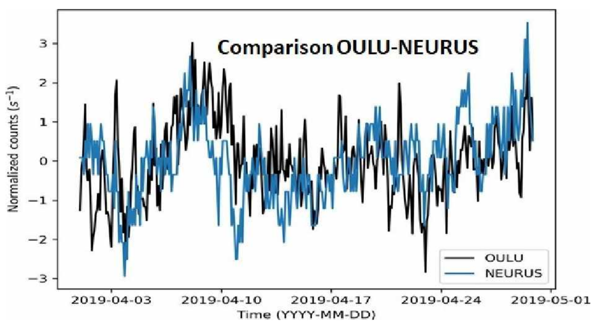

Figure 10: Same period of time measurements of cosmic rays at Oulu neutron monitor in black and Marambio Station Cherenkov Detector in blue, adapted from Santos et al. (2020).

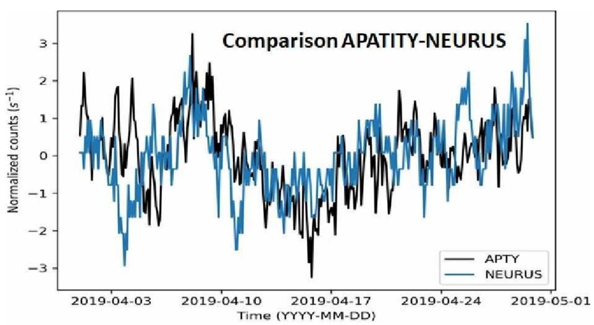

Figure 11: Same period of time measurements of cosmic rays at Apatity neutron monitor in black and Marambio Station Cherenkov Detector in blue, adapted from Dasso et al. (2019b).

rate was compared with the low energy scalers of the Pierre Auger Observatory. Both signals were in good agreement, as can be observed at Fig. 9. So this detector is proven suitable for such studies.

The LAMP Antarctic laboratory was operational since March 2019 (Dasso et al., 2019a). A month of measurements (April) of Neurus particle detector are shown in Figs. 10 and 11 (both adapted from Dasso et al., 2019b; Santos et al., 2020), where the measured rate at Marambio ($Rc \approx 2$ GV) can be compared with the ones observed by neutron monitors at Oulu (similar and lower Rc, $Rc \approx 1$ GV) and at Apatity ($Rc \approx 1$ GV) respectively. As can be seen from both figures, the behavior is quite in agreement, providing validation to the measurements at the LAMP laboratory in Antarctica. The LAMP Observatory is one of the few that was not affected by the pandemic situation and continue in operations with no interruptions. Real time data are available within five minutes, from our Antarctic laboratory to the IAFE server of LAMP in Buenos Aires at the web page `http://lago.iafe.uba.ar/lamp_cosmic_rays`. Figure 12 shows a screen capture of this public site, where relative cosmic rate

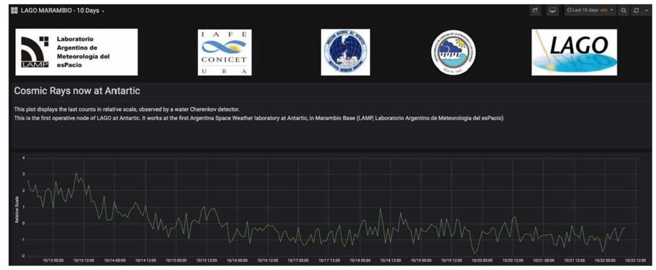

Figure 12: Real Time data of Cosmic Rays measured at Marambio Station.

fluxes are made public for SWx monitoring purposes.

As part of the next steps of this project, LAMP is analyzing the data retrieved in the full first year of operation (Santos et al., 2020). This data are being incorporated to the operative products developed by our group (see Lanabere et al., 2020), along with solar and interplanetary counterpart (see, e.g., Cremades et al., 2018; Dorsch et al., 2020; Gutierrez & Dasso, 2020, among many others) to get a whole panorama of the SWx conditions and the physical processes involved. New possibilities at Argentine Antarctic Southeastern bases are being under consideration to expand the rigidity cutoff values for the cosmic ray particles that can be observed.

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