PROCEEDINGS OF SCIENCE

Izaña Cosmic Ray Observatory

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The Izaña Cosmic Ray Observatory (ICaRO) is a recent facility dedicated to the observation of secondary cosmic rays at the Izaña Atmospheric Observatory (IZO) ($28°18'N$, $16°29'W$, 2373 m a.s.l. and vertical cut-off rigidity of 11.5 GV). It is based on the ORCA design and is able to measure neutrons at two energy thresholds, and muons, their count rates and muon incident direction. The height above sea level and the cut-off rigidity make ICaRO a great detector to fill a gap in the worldwide network of neutron monitors and make it a possible observer of solar neutrons produced during solar events. We present details of its installation as well as the first operational tests.

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1. Introduction

Cosmic rays (CRs) below a few hundred GeV are modulated by solar activity. The Sun can accelerate particles up to tens of GeV. These CRs and solar energetic particles (SEP) can produce secondary particles when they interact with atoms in the atmosphere, and some of these secondary cosmic rays can reach the ground if the primary CR has enough energy. This energy threshold can be about 500 MeV depending on the atmosphere thickness and the cut-off rigidity at the observation point.

Neutron monitors are instruments generally located at ground level to measure secondary neutrons produced by the interaction of cosmic rays and solar energetic particles with atoms in the atmosphere. Neutron detection is based on the capture of thermal neutrons by boron or helium in gaseous counters. This form of detection loses all information about the energy of the incoming neutron and it is the height at which the detector is located and the vertical rigidity cutoff of its geographic location that determines the sensitivity to the flux and energy of CRs and SEPs [1].

Muon telescopes are also suitable instruments to study the cosmic ray flux on Earth by measuring the muons produced by cosmic rays. They follow a different detection technique than the one described for neutron monitors. They are based on ionization produced by charged particles as they pass through an ionization-sensitive volume and are usually composed of several (usually two) stacked sensitive planes to form a true telescope. They are usually operated in coincidence and the combination of different detection devices in both planes allows the determination of the direction of incidence of the muons [2].

Both instruments are complementary since neutron monitors are sensitive to CR energies from 0.5 GeV to 50 GeV and muon telescopes have a relevant response to CRs from 10 GeV to several hundred GeV. An example of this complementarity can be seen at the Antarctic Cosmic Ray Observatory (ORCA) at the Spanish Antarctic Base Juan Carlos I located on Livingston Island. [3].

The Izaña Atmospheric Observatory (IZO), managed by the Izaña Atmospheric Research Centre which is a centre of the State Meteorological Agency (AEMET), is at Tenerife island at $28°18'N$, $16°29'W$, 2373 m a.s.l (Figure 1). The observatory is located on the top of a mountain plateau. IZO is normally above a temperature inversion layer, which is generally well established over the island, and consequently free of local anthropogenic influences. IZO conducts observations and research related to atmospheric constituents that are capable of forcing change in the climate of the Earth (greenhouse gases and aerosols), which may cause depletion of the global ozone layer, and that play key roles in air quality from local to global scale. IZO has contributed to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) Programme (https://public.wmo.int/en) since its establishment in 1989. GAW integrates a number of WMO research and monitoring activities in the field of atmospheric environment, and its main objective is to provide data and other information on the chemical composition and related physical characteristics of the atmosphere and their trends. IZO also contributes to international networks and databases such as the Network for the Detection of Atmospheric Composition Change (NDACC), Total Carbon Column Observing Network (TCCON), Aerosol Robotic Network (AERONET), Baseline Surface Radiation Network (BSRN), NASA Micro-Pulse Lidar Network (MPLNET), World Data Centre for Greenhouse Gases (WDCGG) or National Oceanic and Atmospheric Administration - Earth System Research Laboratories (NOAA - ESRL). A detailed description of the IZO facilities and all

Figure 1: Izaña Observatory.

Figure 2: *Hangar de Cometas*: ICaRO's home.

Table 1: ICaRO components

	ICRO (3NM64)	ICRB (3BNM)
Counter Type	BP28	LND2061
Effective diameter (mm)	148.5	149.1
Effective length (mm)	1908.0	1956.3
Cathode material	Stainless steel	Stainless steel
Gas filling	$BF_3(96\%\ ^{10}B)$	$BF_3(96\%\ ^{10}B)$
Gas pressure (mmHg)	200	200
Operational voltage (V)	-2700	1800
	ICRM Top	ICRM Bottom
Scintillator	BC400 (Polyvinyltoluene)	BC400 (Polyvinyltoluene)
Dimension (cm)	100x100x5	100x100x5
Operational voltage (V)	1000	1000
PMT	4 R2154	4 R2154
	Vaisala Meteorologic station	
PTU 301	500-1100 hPa	$\pm 0.05 hPa$
Pt100	-40 to 60°C	$\pm 0.2°C$
HUMICAP 180C	0-100%	±1%

the observation and research programs at the station can be found in [4].

2. ICaRO

The Izaña Cosmic Ray Observatory is a cosmic ray detector located at IZO (2373 m a.s.l), with a vertical cut-off rigidity of 11.5 GV. It is based in the ORCA design [3] and, as ORCA, is made by a set of detectors to measure neutrons and muons produced in the atmosphere by cosmic rays and SEPs. It is housed into the *Hangar de Cometas* building (Figure 2). A diagram of ICaRO/ORCA can be seen in Figure 3.

A meteorological station, two neutron detectors, ICRO and ICRB, and a muon telescope,

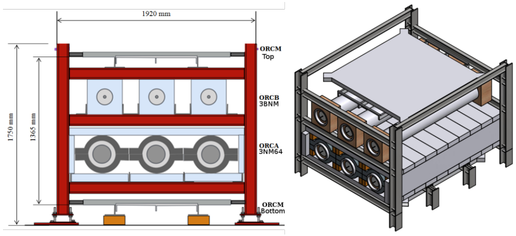

Figure 3: ORCA diagram. ICaRO has an identical configuration.

Figure 4: Picture of ICaRo.

ICRM, form ICaRO. ICRO is a standard 3NM64 neutron monitor, ICRB is a set of three boron trifluoride (3BNM) bare counter tubes and ICRM is a muon telescope based on the MITO design [5], which consists of two $1m^2$ scintillators, one at the top of ICaRO and the second at the bottom (see Figure 3). The technical characteristics are shown in Table 1.

The muon telescope in ICaRO is based on the Muon Impact-Tracer Observer (MITO) [5]. This is a telescope composed by a stack of two BC-400 organic scintillators (100 cm x 100 cm x 5 cm, polyvinil-toluene with a light output 65% of that of antrhacene), placed at the top and bottom of a metallic structure (and thus, named Top and Bottom), 136.5 cm apart FROM each other, with ICRB and ICRO, and therefore, a 10 cm layer of lead in between (dark grey rings around ICRO tubes in Figure 3).

Four photomultiplier tubes (PMTs) are coupled to each scintillator by means of a pyramidal light guide. Each PMT collects the light reaching the corresponding lateral surface of the scintillator and generates a pulse whose amplitude is related to the distance between the particle impact point and the corresponding lateral surface of the scintillator. The particle trajectory is reconstructed by combining the computed impact points at Top and Bottom.

ICRM provides one minute count rates for four coincidence configurations and the particle impact point on each scintillator. The coincidence configurations are: Top: the four PMTs in the upper scintillator, Bottom: the four PMTs in the bottom scintillator, Coin8: the eight PMTs, i.e. particles that cross both scintillators, and Lateral: a combination of two PMTs in the upper scintillator located at a common lateral side and two PMTs in the bottom scintillator but at the opposite lateral side. These four coincidence configurations can be changed to any possible combination of the eight PMTs. As it was stated above, it is possible to establish a relationship between the particle impact point on the scintillator plane and the light gathered through the opposite lateral sides [5]. A different approach to the estimation of the impact point based on a neural network approach can be found in [6].

ICRO and ICRB provide one-minute neutron count rates. Because of their physical configuration, i.e., surrounded by lead tubes versus bare tubes, the energy threshold for neutron detection is different for ICRO and ICRB. On the other hand, neutrons and muons are produced by cosmic rays with different energy thresholds above $\approx$ 500 MeV for neutrons and above $\approx$ 10 GeV for muons. This makes possible to observe the change in the cosmic ray spectrum in this narrow range, which

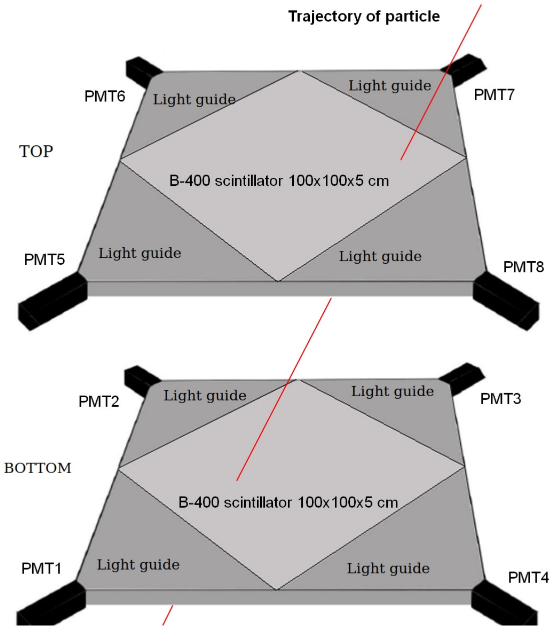

Figure 5: ICRM scintillator arrangement. The black prisms are the 8 PMTs, the 8 light guides are in darker grey and scintillators in light grey. This figure has been adapted from [5].

Table 2: Preliminary fit parameter β for ICaRO's instruments

Instrument	ICRO	ICRB	ICRM-Top	ICRM-Bottom	ICRM-coin8
β in hPa^{-1}	0.009 ± 0.0003	0.0098 ± 0.0008	0.0015 ± 0.0001	0.012 ± 0.002	0.0049 ± 0.0002

is important when a solar event changes the usual flux of CRs and SEPs.

3. First data

ICaRO was installed at the Izaña Atmospheric Observatory in end of February 2023. On March 12^{th} 2023 a failure was detected in both ICRO and ICRM which was resolved on May 4^{th}. Although ICaRO is still in commissioning, it is providing stable data since then.

Although the measurement period is short (2 months at the time of ICRC2023), some preliminary data are available, and an initial pressure correction has been performed for ICRO and ICRB, i.e. the neutron monitors (Figures 6 and 7). The same has been done for Top, Bottom and coin8. Data from 2023-05-09 to 2023-05-31 have been used to make the adjustments. The small amount of data makes it necessary to use them with caution.

Pressure Correction parameter β is shown in Table 2. These values are very preliminary. It is clear that ICRM-Bottom shows an anomalous value. More data are mandatory to estimate the β parameter. Nevertheless, all the instruments show the expected pressure dependence.

Although ICaRO is providing very preliminary data, in early May it observed the FD that was also observed by NMDB. The Figure 8 shows hourly data from CaLMa that serve as a comparison with the ICRO data and show that ICaRO observed the final part of the FD decrease phase and the entire recovery phase.

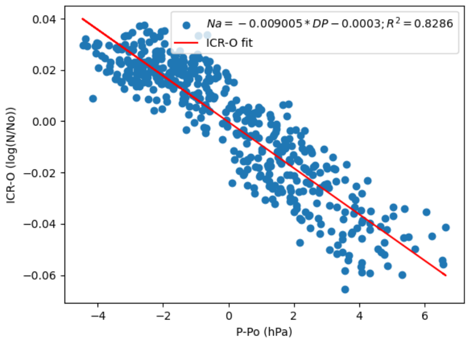

Figure 6: ICRO: count rate vs. pressure and fit line (red continuous line).

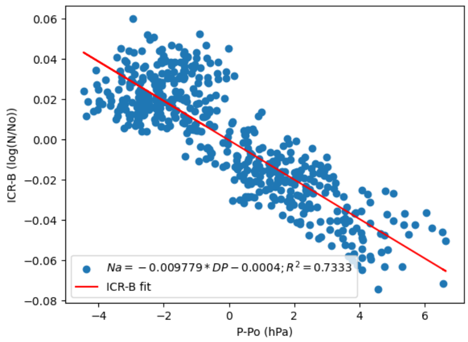

Figure 7: ICRB: count rate vs. pressure and fit line (red continuous line).

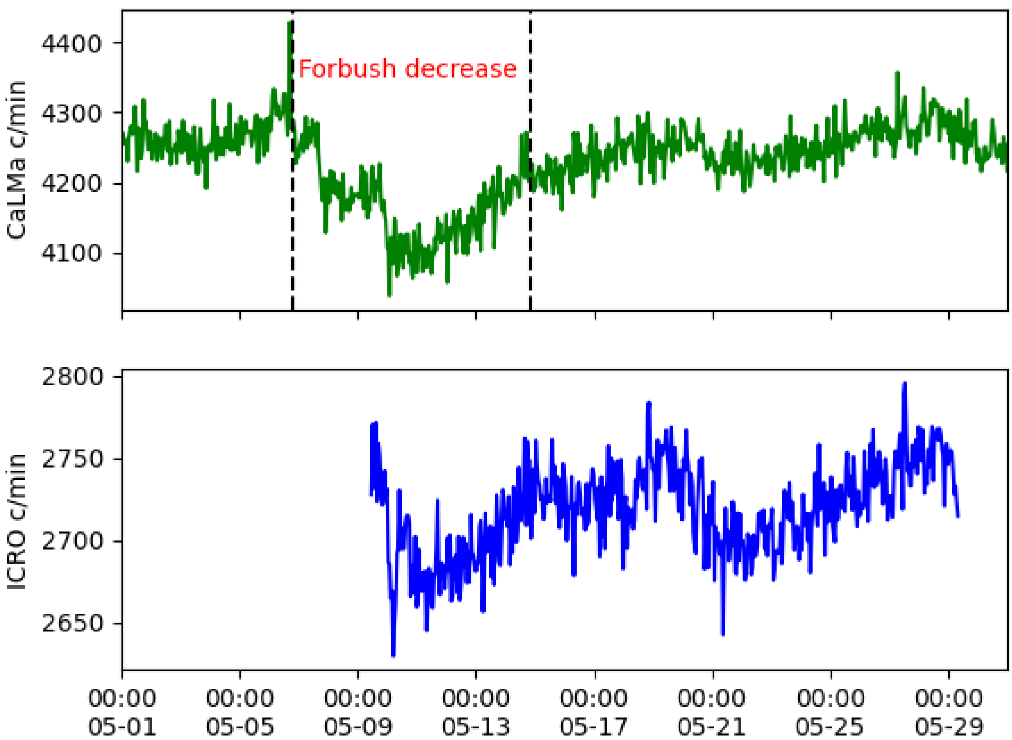

Figure 8: Decrease in Forbush observed by CaLMa in early May (top panel). Pressure-corrected ICRO measurements. The lack of data in early May was due to a problem in the acquisition system although this did not prevent partial observation of FD in ICaRO.

4. Conclusions

A new cosmic ray detector is in operation at the Izaña Atmospheric Observatory. Its objectives are to follow solar activity, to study the interactions between cosmic rays and solar energetic particles with the atmosphere and to be a useful instrument for space weather related issues.

ICaRO was installed on the end of February 2023 and has been fully operational since mid-May. However, it is in the commissioning phase and the data must be handled with caution at this time.

Acknowledgments

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References

[1] J.A. Simpson, *The cosmic ray nucleonic component: The invention and scientific uses of the neutron monitor – (keynote lecture)*, *Space Science Reviews* **93** (2000) 11.

[2] M.L. Duldig, *Muon observations*, *Space Science Reviews* **93** (2000) 207.

[3] J.J. Blanco, J.I. García-Tejedor, Óscar García-Población, S. Ayuso, A. López-Comazzi, I. Vrublevskyy et al., *Cosmic ray observations from livingston island*, *Advances in Space Research* **69** (2022) 3514.

[4] E. Cuevas, C. Milford, J.J. Bustos, O.E. García, R.D. García, A.J.G. Peláez et al., *Izaña atmospheric research centeractivity report 2017-2018*, Tech. Rep. Joint publication of State Meteorological Agency (AEMET)and World Meteorological Organization (WMO), WMO/GAW Report No. 247 (2019), DOI.

[5] S. Ayuso, J.J. Blanco, J.I. García-Tejedor, R. Gómez-Herrero, I. Vrublevskyy, O. García-Población et al., *Mito: a new directional muon telescope*, *J. Space Weather Space Clim.* **11** (2021) 13.

[6] A. Regadío, J.I.G. Tejedor], S. Ayuso, Óscar [García Población], J.J. Blanco, S. Sánchez-Prieto et al., *Trajectory determination of muons using scintillators and a novel self-organizative map*, *Nucl. Instrum. Methods Phys. Res. A* **973** (2020) 164166.

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