PROCEEDINGS OF SCIENCE

Data publication activities for the Global Muon Detector Network (GMDN)

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Solar modulation studies by ground-based muon and neutron detectors are closely related to atmospheric and space environment sciences, and sharing research data has been a common approach to reveal these complex systems. The Global Muon Detector Network (GMDN) has recently finalized the archival dataset downloadable on the website. It is also notable that the concept of open data and cross-disciplinary research is becoming a major trend in all scientific fields, sometimes called "open science." Leveraging this situation, we are upgrading our data publication strategy in collaboration with outside platforms. The GMDN archival data was registered to Shinshu University's institutional repository and provided a permanent digital object identifier. This registration also made the GMDN data findable in the dataset search engines such as Google Dataset Search. Moreover, we prepared our observational data and its metadata in scientific standardized formats, Common Data Format (CDF) and Space Physics Archive Search and Extract (SPASE) schema respectively. CDF features a self-describing format where the metadata is combined with numerical data for consistency. This standardized format also allows us to use data analysis frameworks, such as Space Physics Environment Data Analysis Software (SPEDAS). The CDF data and SPASE metadata were published on the IUGONET database, which supports SPEDAS with its own plugin software. It will also appear in more interdisciplinary database, Advanced Multidisciplinary Integrated-Database for Exploring new Research (AMIDER) which collaborates with IUGONET. We report these data publication activities aiming to contribute to the open and fusion sciences based on cosmic-ray physics.

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1. Introduction

Cosmic-ray muons feature the highest statistics (flux) on the ground. It allows us to detect a temporal variation and angular distribution (anisotropy) of cosmic rays, both of which have a typical size below $\sim$ 1% in the $\sim$ 10 GeV region. The muon's strong penetration power compared with other particles, such as neutrons, also leads to an excellent sensitivity of muon observations to the anisotropy. This makes muon observation a unique means to study cosmic-ray propagation physics based on the phase-space distribution of cosmic rays. The cosmic-ray propagation in the magnetized plasma is basically described by the Boltzmann equation for the phase-space distribution, called the solar modulation of cosmic rays in the case of the heliospheric propagation, and also involves space weather phenomena such as coronal mass ejections (CMEs) and interplanetary shocks.

The Global Muon Detector Network (GMDN)[1] combines wide angular acceptance and high statistics for cosmic rays, thanks to its detector network, each with $\geq$ 25 m^2 detection area, and distributed across multiple countries in both longitude and latitude. The GMDN achieved its initial goal of construction in 2016 by expanding the Kuwait detector. The network further continues to expand, including the Syowa Station detector, which has been operated since 2018 in Antarctica. Some stations, such as the Nagoya muon detector, also feature the extended observation period over two solar cycles (>40 years).

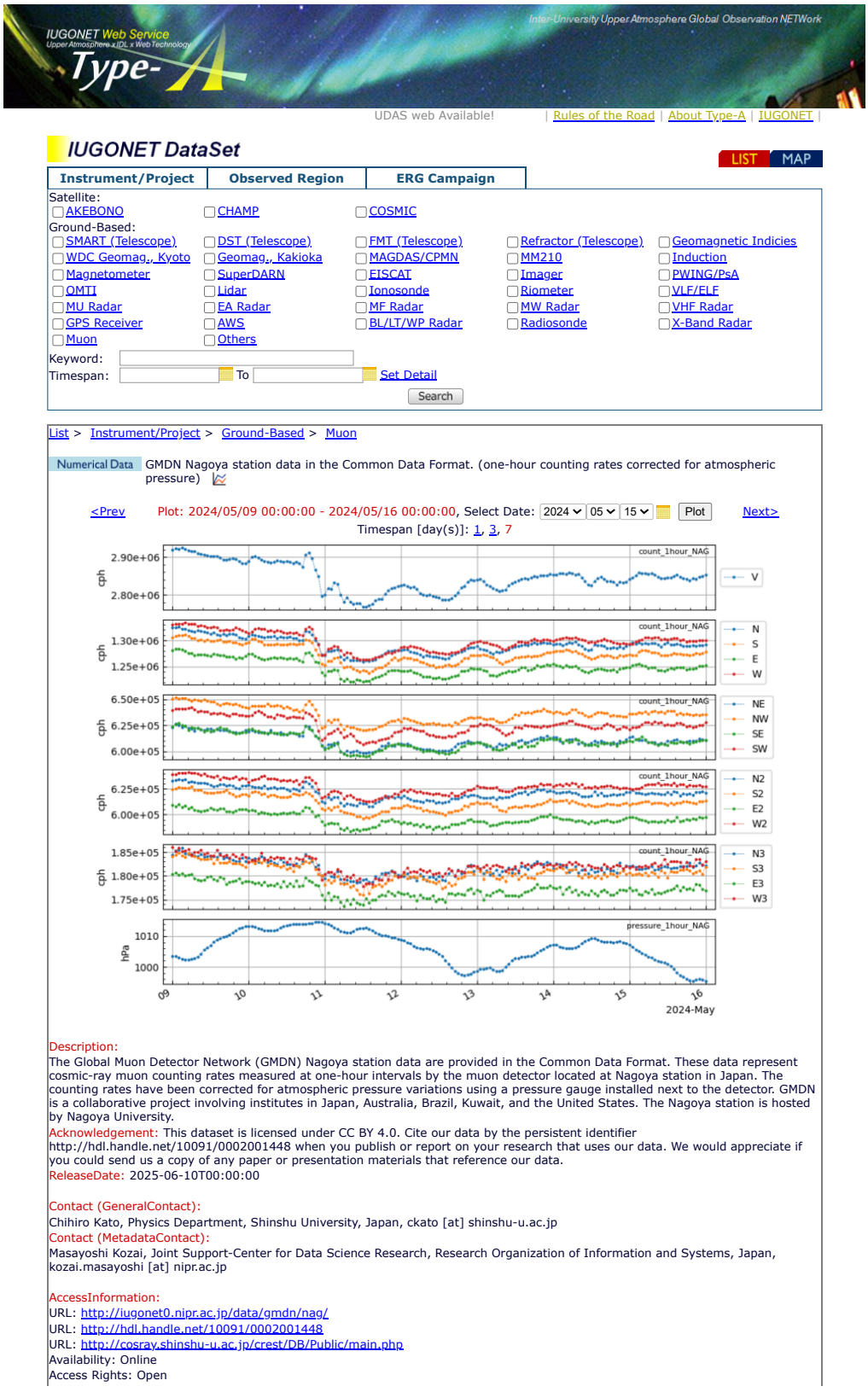
Cosmic-ray propagation studies with ground-based muon and neutron detectors are closely related to atmospheric and space environment sciences, and sharing research data has been a common approach to reveal these complex systems. The typical cases are the World Data Centre (WDC) system and WDC-CR[2] triggered by the International Geophysical Year (IGY) in 1957-1958. NMDB[3] is also one of the representative databases for neutron monitors. OMNIWeb[4] is also widely used to access the space environment data. It is notable that the concept of open data and interdisciplinary research is becoming a major trend in all scientific fields, sometimes called "open science." In addition to the well-established scientific databases above, interdisciplinary scientific databases or platforms have recently been developed by national projects or researchers' consortia, driven by such a trend.

GMDN has recently finalized the archival dataset after extensive data cleaning for >20 years of hourly (or minute) data. Based on these established data, we are upgrading the GMDN data publication strategy by taking full advantage of the interdisciplinary scientific platforms, as reported in this paper.

2. Methods and results

We first registered the GMDN archival data to Shinshu University's institutional repository and provided a persistent identifier (http://hdl.handle.net/10091/0002001448). The institutional repository is under the academic inter-institutional service in Japan, JAIRO Cloud[5], and the GMDN

[1] https://cosray.shinshu-u.ac.jp/crest/DB/Public/main.php
[2] https://cidas.isee.nagoya-u.ac.jp/WDCCR/
[3] https://www.nmdb.eu/
[4] https://omniweb.gsfc.nasa.gov/
[5] https://jpcoar.repo.nii.ac.jp/



Description:
The Global Muon Detector Network (GMDN) Nagoya station data are provided in the Common Data Format. These data represent cosmic-ray muon counting rates measured at one-hour intervals by the muon detector located at Nagoya station in Japan. The counting rates have been corrected for atmospheric pressure variations using a pressure gauge installed next to the detector. GMDN is a collaborative project involving institutes in Japan, Australia, Brazil, Kuwait, and the United States. The Nagoya station is hosted by Nagoya University.
Acknowledgement: This dataset is licensed under CC BY 4.0. Cite our data by the persistent identifier http://hdl.handle.net/10091/0002001448 when you publish or report on your research that uses our data. We would appreciate if you could send us a copy of any paper or presentation materials that reference our data.
ReleaseDate: 2025-06-10T00:00:00

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AccessInformation:
URL: http://iugonet0.nipr.ac.jp/data/gmdn/nag/
URL: http://hdl.handle.net/10091/0002001448
URL: http://cosray.shinshu-u.ac.jp/crest/DB/Public/main.php
Availability: Online
Access Rights: Open

Figure 1: Web page of the Nagoya muon detector data in CDF published on IUGONET.

data became accessible via dataset search engines such as Google Dataset Search or CiNii Research[6], by their metadata harvesting. It is also an important achievement that the license and terms of use for this data were formally established under the international standard and the institutional repository's policy, as seen in the landing page linked by the persistent identifier. This will avoid future conflicts concerning data use, such as an insufficient citation to the data.

We also prepared the GMDN data in Common Data Format (CDF)[7]. CDF is a standardized data format by NASA for space physics data and features a self-describing format where each observational data is combined with its metadata for their consistency. It is a platform-independent binary format compatible with various languages and machine environments. Along with this data conversion, detailed metadata was created following the Space Physics Archive Search and Extract (SPASE)[8] data model, which is a standardized schema organized by the SPASE consortium for heliophysics data. These standardizations of data and metadata enable the GMDN data to be handled by a wider range of databases and analysis frameworks. Aiming at maximizing advantages of these data formats, we have started to register the standardized GMDN data on the Inter-university Upper atmosphere Global Observation NETwork (IUGONET)[9] data service [1–4]. IUGONET is based on an integrated database for solar-terrestrial physics and is widely used by the space weather and upper atmospheric science communities. The Nagoya muon detector data has been available on IUGONET at https://search.iugonet.org/metadata/001/00003723 ahead of other stations. It is also findable by selecting "Muon" in the preset keywords on the IUGONET data service[10]. As default functions of IUGONET, the Nagoya dataset page above provides a quick view of data plots, link for the CDF data download, definitive metadata display based on the SPASE schema, and the SPASE-based metadata download in XML, as shown in Figure 1. The DOI assignment to this dataset is also ongoing with the support of IUGONET.

IUGONET also supports Space Physics Environment Data Analysis Software (SPEDAS)[11], a data analysis framework for space physics. SPEDAS provides loading, visualization, analysis, and integration of cross-mission CDF datasets. We have developed a SPEDAS-based python module for the GMDN data and preliminarily published it on https://doi.org/10.5281/zenodo.15629341. Figure 2 shows a demonstration of this module which is also accessible in this link. Its integration to the IUGONET's official plugin for SPEDAS, UDAS[12] is ongoing and this integration will enable cross-analyses of the GMDN data with diverse datasets in the space and earth science.

It is also notable that IUGONET is collaborating with the Advanced Multidisciplinary Integrated-Database for Exploring new Research (AMIDER) project [5] whose database is available in https://amider.rois.ac.jp/. AMIDER is a more multidisciplinary scientific database aiming at making research data open for non-expert users. The GMDN data will be available in AMIDER, followed by the UGONET registration.

[6] https://cir.nii.ac.jp/
[7] https://cdf.gsfc.nasa.gov/
[8] https://spase-group.org/
[9] http://www.iugonet.org/
[10] http://search.iugonet.org/
[11] https://spedas.org/wiki/
[12] https://www.iugonet.org/product/analysis.jsp

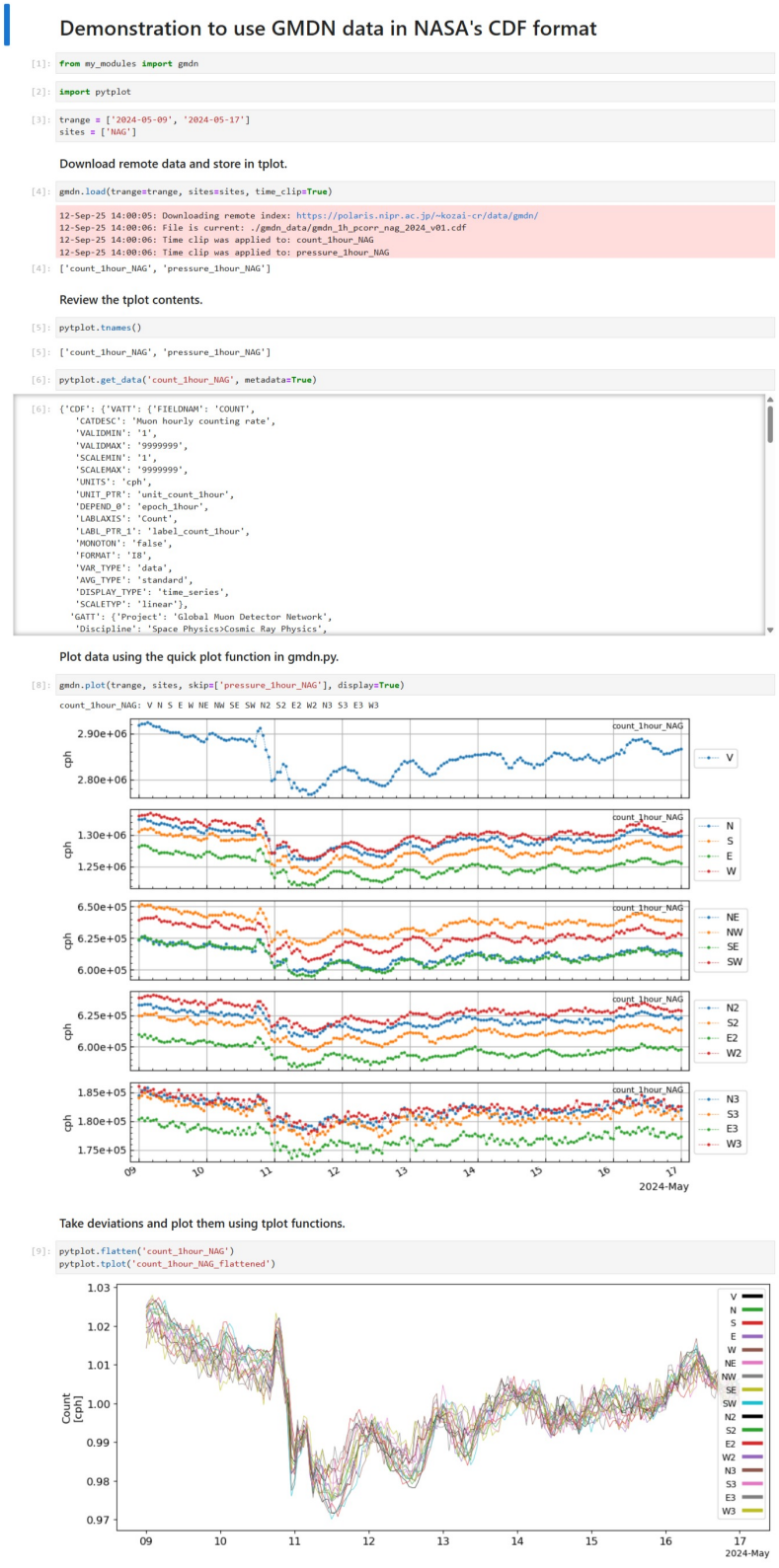

Figure 2: Demonstration to load and plot the GMDN data in CDF using a SPEDAS-based python module.

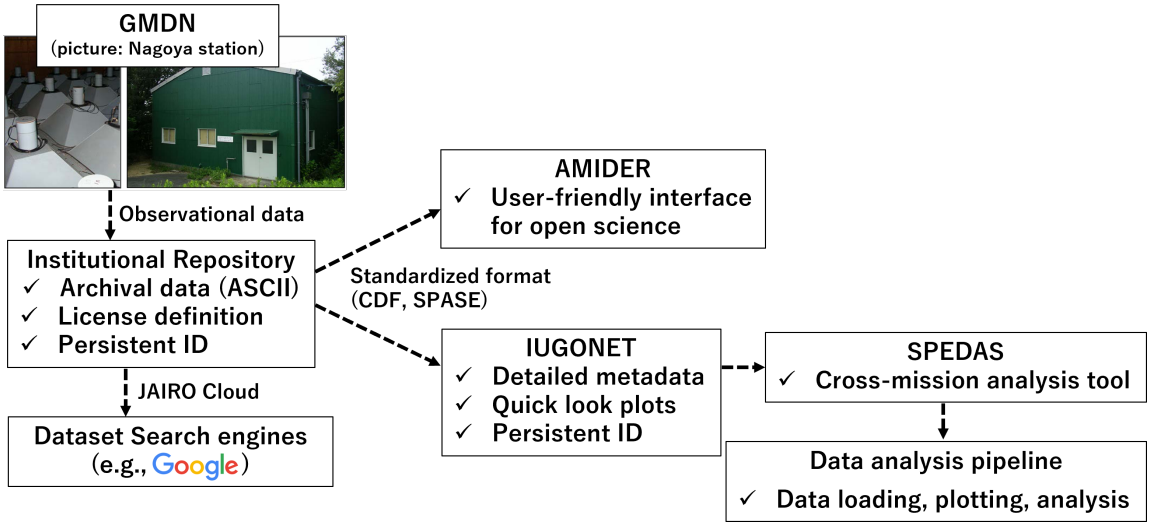

Figure 3: Conceptual diagram of the current GMDN data management and publication activity.

3. Summary

Figure 3 depicts the summary of the current GMDN data management and publication activity. The archival datasets were finalized by extensive data cleaning for the long-term observational data and published in Shinshu University's institutional repository. The license for data usage was defined, a persistent ID was provided, and the data became findable in dataset search engines such as Google Dataset Search via JAIRO Cloud. The observational data and their metadata were standardized into the CDF and SPASE formats, enabling their exchange beyond the cosmic-ray physics community. These data for Nagoya muon detector is now available on the IUGONET data service, followed by other station data. By handling the CDF data with the cross-mission analysis framework, SPEDAS, users can easily build a seamless data analysis pipeline, including data loading, plotting, and analysis, without being bothered by data format issues. This provides benefits to both interdisciplinary researchers and cosmic-ray experts. These inter-operations of the GMDN data between interdisciplinary platforms (institutional repository, IUGONET, AMIDER, etc.) will enhance the data visibility and accessibility, and contribute to the open and fusion science based on cosmic-ray physics.

Acknowledgments

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