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The capacity-building and science-enabling activities of the IUGONET for the solar-terrestrial research community

Akiyo Yatagai[1*], Yuka Sato[2], Atsuki Shinbori[3], Shuji Abe[4], Satoru UeNo[5] and IUGONET project team

Abstract

Background: This paper presents an overview of the capacity-building activities and science-enabling services of the Inter-university Upper atmosphere Global Observation NETwork (IUGONET) project. This Japanese program, which started in 2009, is building a metadata database (MDDB) of ground-based observations and is developing an analysis software to handle the data linked to the MDDB system for use by the solar-terrestrial physics community. Because the institutional members of the IUGONET are mainly universities in Japan, we explore tools that can contribute to advanced education as well as promote research activities.

Findings: In this paper, we describe the utilities of the IUGONET for education, including our capacity-building activities in developing countries. We have regularly facilitated training seminars for Japanese students on the use of our tools (IUGONET MDDB and the software), and we have held capacity-building seminars for young scientists in developing countries. In addition to the MDDB, we have prepared various 'gateway' tools for users who are unfamiliar with 'keywords' to search for data. One of these is a geographical display tool that uses Google Earth (KML file), which is included as supplemental material to this paper. The usefulness of the IUGONET has been proven over its first 5 years of operation by the increasing number of its users, which has led to the production of approximately 500 scientific papers, including 42 thesis papers.

Conclusions: The IUGONET community collaborates with the Scientific Committee on Solar-Terrestrial Physics program, not only in its scientific activities, but also in the establishment of E-infrastructure and capacity building.

Keywords: Ground-based observation; Solar-terrestrial physics (STP); Database; Metadata; Interdisciplinary studies; Capacity building; E-infrastructure

Findings

Background of data activities of the STP community

The series of the Climate And Weather of the Sun-Earth System (CAWSES) projects of the Scientific Community on Solar-Terrestrial Physics (SCOSTEP) required considerable standardization efforts to unify the variety of ground-based and satellite-derived observational data obtained across disciplines and countries (CAWSES Office 2014; Davila and Tsuda 2014). The solar-terrestrial physics (STP) research community handles diverse data resources that span the globe, reach altitudes over 100 km into the heliosphere, and extend over many decades in duration. To complicate matters further, the sophistication of ground-based and spaceborne observatories for remote and *in situ* sensing of the STP domain results in the archives of these data resources being distributed among various organizations throughout the world. This has culminated in the long-standing challenges associated with centralized STP data exchange and distribution. It is the responsibility of the CAWSES program to preserve observational data that are spread across individual institutions and to help students and early career scientists from different backgrounds to obtain data relevant to their research.

The International Council of Scientific Unions (ICSU)/World Data Center (WDC) for STP was established in 1957 to manage data collected during the International

* Correspondence: akiyoyatagai@stelab.nagoya-u.ac.jp
[1]Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
Full list of author information is available at the end of the article

Geophysical Year (IGY, 1957 to 1958) to avoid catastrophic damage to all the observed geophysical data. This system has evolved over the approximately 60 years of its operation for the STP community, especially in Japan. The Space Physics Interactive Data Resource (NOAA National Geophysical Data Center 2014) of the former WDC for Solar-Terrestrial Physics, Boulder, in the National Geophysical Data Center (NGDC)/National Ocean and Atmosphere Administration (NOAA), is the pioneer database for archiving STP observational data. Satellite mission data from the upper atmosphere and heliosphere have been archived at the National Space Science Data Center (NSSDC) of the National Aeronautics and Space Administration (NASA) (Grayzeck 2014) since 1966. These include the Virtual Magnetospheric Observatory (VMO), Virtual Heliospheric Observatory (VHO), and Virtual Solar Observatory (VSO), which constitute satellite data archives for each field and are NASA projects that are grouped under the abbreviated name 'VxO.'

Solar data have been archived mainly at the VSO (Gurman 2014), and this system, which includes a data exchange function, has become a community tool for solar scientists.

In terms of the analysis system, the Coordinated Data Analysis (Workshop) Web system of NASA (McGuire 2014) enables researchers to handle key parameters and statistics of STP as well as observed data prepared by the VxO. In the United States, for ground-based observations, the incoherent scatter radar community has started the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program database, and the CEDAR Madrigal database (Rideout 2014) is currently collecting international upper atmospheric observational data and/or metadata obtained in South America, Europe, China, and the United States, in addition to providing analysis software.

Necessity for the IUGONET metadata system

Long-term ground-based, i.e., stable, observational data are of considerable importance because the upper atmosphere is strongly affected by solar activity. The STP research community of Japan does not have any central institutions for data exchange and distribution, as mentioned above. Thus, the observational data from solar telescopes, various radars, optical instruments, and magnetometers are held mainly by the relevant institutions. This means that it is difficult for early career scientists from different backgrounds to obtain data for their research work. Hence, in 2009, the leading institutions of the National Institute of Polar Research, Tohoku University, Nagoya University, Kyoto University, and Kyushu University started the Inter-university Upper atmosphere Global Observation NETwork (IUGONET) project for managing ground-based observations of the upper atmosphere and the Sun.

The primary objective of the IUGONET project was to build a metadata database (MDDB) for ground-based observations of the upper atmosphere, which could be searched by a dedicated analysis software for relevant observed data (Hayashi et al. 2013). However, we deal with data pertaining to both the Sun as well as the upper atmosphere.

The IUGONET was quickly able to fulfill its original purpose of developing an MDDB and analysis software (Yatagai et al. 2014). Currently, the IUGONET is expanding to provide additional tools for related geoscience fields and the international CAWSES society, including developing countries, not just the member institutions and domestic Japanese STP community. The general activities of the IUGONET and developed products have been described elsewhere (Tanaka et al. 2013; Yatagai et al. 2014), including this volume (Abe et al. 2014).

The IUGONET project team has provided exhibitions at various meetings and committed considerable investments of time, manpower, and funds to enhance the capacity-building aspects of the data service for students of all levels, as well as established scientists unfamiliar with the IUGONET. Figure 1 shows the activities and general flow of the data in the IUGONET.

This paper will discuss the capacity-building and science-enabling activities of the IUGONET because these have been important topics for the CAWSES-II program. We will first briefly describe the data resources and then outline our educational and capacity-building activities for developing countries. This will be followed by a statistical analysis of the science-enabling capability of the IUGONET, together with a discussion of the overarching objectives for future developments.

Diversity of the IUGONET data resources

The IUGONET MDDB is built as a metadata repository based on the Space Physical Archive Search and Extract (SPASE, King et al. 2010) model, which is widely used in the international STP community, such as NASA's VxOs. While the primary focus of the VxO projects is on satellite data, the IUGONET has made a systematic effort to acquire data resources from assorted ground-based instrumentation, including the digitization of analog data stored on paper and magnetic tapes. Thus, the IUGONET has become a unique repository of ground-based STP data at more than 860 observatories worldwide (Figure 2).

IUGONET data search and various gateways

The IUGONET metadata (MD) are written in XML format, and the style (or format) is defined for individual keywords (Observatory, Instrument, Person, Dataset,

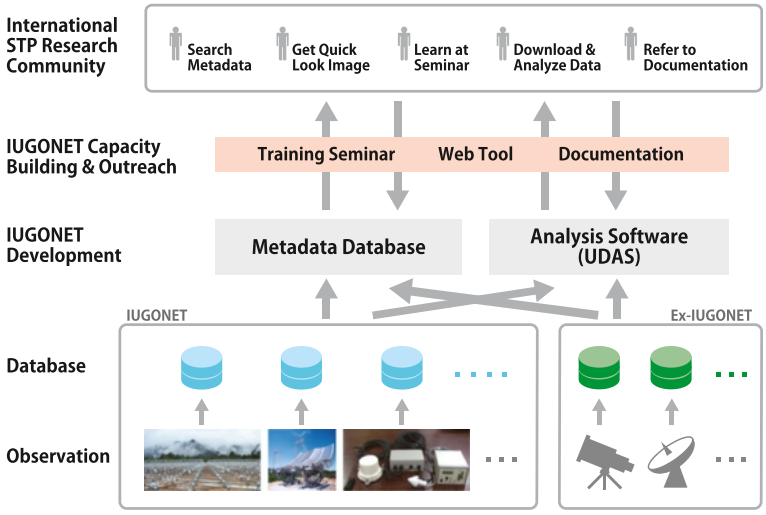

Figure 1 Data flow and capacity-building/outreach of the IUGONET. The observational data are archived in each institutional database, and the metadata database and analysis software (UDAS) are developed. Some educational activities are performed in this development part of the IUGONET. These developed products are used for the international STP research community, including those in developing countries.

and Granule to reach each specific data file), in accordance with the SPASE ontology. Because these MD are formatted uniformly, conversion to another format (including KML) is relatively simple.

Figure 3 shows an example of how the Observatory MD function with Google Earth to display the information on the observation, for example, in the region including Kyoto and Nagoya, Japan. Many instruments at Shigaraki Observatory are displayed by browsing (not shown). For instance, if the Optical Mesosphere Thermosphere Imager (OMTI; an all-sky imager at Shigaraki) is chosen, the MD of the instrument appear on screen (Figure 3b). By

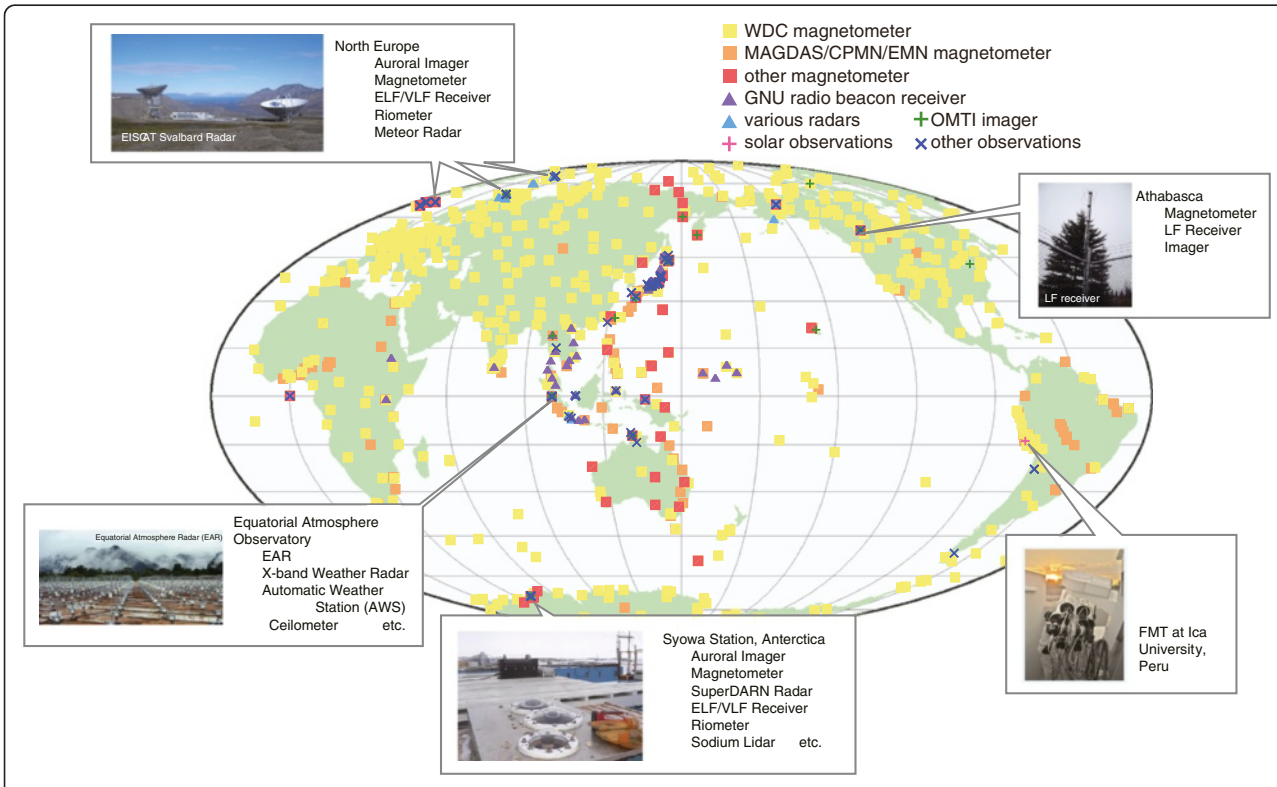

Figure 2 Global network of ground-based observations that are registered to the IUGONET system.

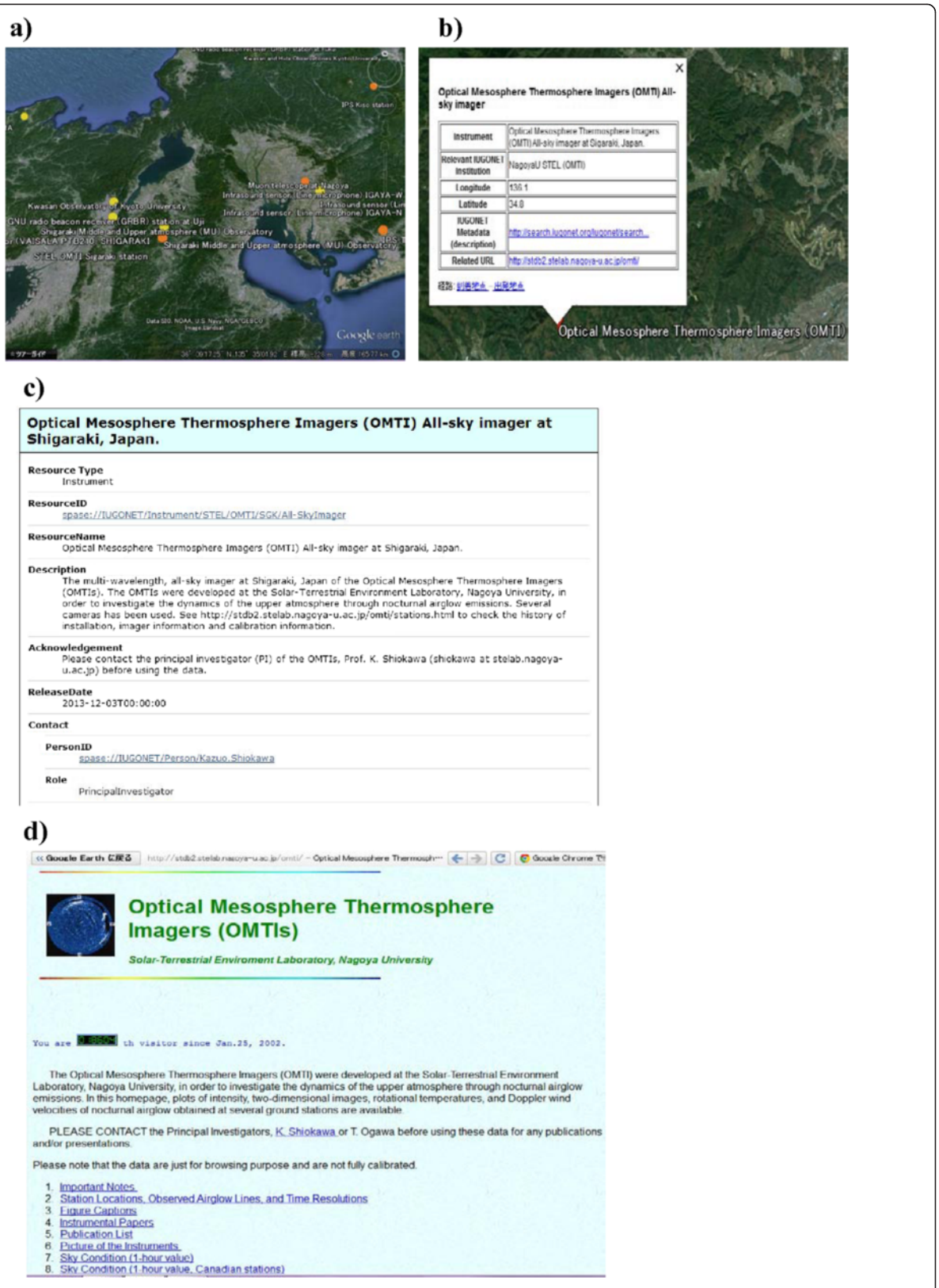

Figure 3 (See legend on next page.)

(See figure on previous page.)
Figure 3 Observatories and instruments registered in IUGONET MDDB as viewed through Google Earth around Kyoto and Nagoya, Japan. (a) Observatories. Yellow indicates observatories operated by Kyoto University, and orange indicates those operated by Nagoya University. **(b)** Display of the metadata of the all-sky camera of OMTI at Shigaraki, offered by clicking 'Instrument' metadata viewed through Google Earth. **(c)** Result of search MDDB followed by clicking IUGONET Metadata (description) in **(b)**. **(d)** Result of clicking 'Related URL' shown in **(b)**.

clicking the associated web address, the user can obtain descriptions of the MD (Figure 3c) and related URLs, e.g., OMTI's webpage (Figure 3d).

From these tables and the KML file, users can easily recognize the types of data installed in the IUGONET MDDB and find appropriate keywords, for example, 'SuperDARN', 'OMTI', and 'all-sky camera'. The geographical tool mentioned above received much attention from scientists attending inter-disciplinary meetings and workshops (described later). We include this KML file, used for displaying the observatory and instrument MD, as supplementary material for this paper (see Additional files 1 and 2).

A team comprising ten PhD-level researchers is affiliated with the IUGONET development team. They work to create the MD by extracting relevant information from scientific papers and technical documents and by interviewing the relevant data holders. Thus, all the IUGONET resources are linked to meta-information such as 'Description' and 'Keyword' text files, and new users can be navigated quickly to the wealth of data resources using the IUGONET tools. As illustrated earlier (Figure 3), the MD are valuable for explaining the data to newcomers and for various outreach/capacity-building activities.

We prepared a list of the registered MD (IUGONET 2014a) using a function of Google Spreadsheet, as shown in Figure 4. This provides users with knowledge of both types of data: those registered already in the MDDB and those in preparation for release. In addition, it is useful for newcomers as it offers them a selection of suggested keywords to be entered. This is because some keywords are linked to the search results of each deterministic portion of meta-information; therefore, this sheet is instructive in explaining our MDDB.

As shown in Figure 4, if an all-sky monochromatic image dataset is chosen (Figure 4a, red square), the MD of that dataset appear on the screen (Figure 4b), which provides users with a description of the data. If granule MD is registered (e.g., SuperDARN, Figure 4c), one can reach the original data without restriction. If the data-handling software, iUgonet Data Analysis Software (UDAS, described in the following) is available, this is written as 'Load routine for UDAS is available' in the column. By clicking the 'Note' shown on the screen (Load routine for UDAS is available), the user can go to the list of the 'load procedure' of UDAS (Figure 4d).

Development and use of the UDAS software

A suite of custom software was developed to support downloading, plotting, and analysis of data registered in the IUGONET database (IUGONET 2014b). The IUGONET does not regulate individual data formats employed by its member institutes. Instead, in collaboration with the Exploration of Energization and Radiation in Geospace Science Center (Miyoshi et al. 2012), we have developed the UDAS software to handle various types of formatted data using the same platform (Tanaka et al. 2013).

As a part of the IUGONET activities, an institutional educational program (Bachelor and Master's course level) participates in the development of an analysis package in the UDAS. For example, various types of statistical tests of significance have been incorporated into the UDAS (Hamaguchi 2013). The UDAS is useful not only for researchers in terms of handling data (downloading, producing graphs, analyzing), but also for participating in its development of the IUGONET system.

Domestic training seminars and overseas capacity building

The IUGONET has facilitated a series of domestic training seminars for the STP community's early career scientists, as well as more experienced researchers who want to handle data by means of a graphical user interface, on how best to use the UDAS (and MDDB). In addition to regular annual or biannual training seminars, IUGONET developers are conducting small training seminars at several universities.

As shown in Figure 2, IUGONET institutions have been performing ground-based observations for a long time and they have established many observatories throughout the world. To promote the use of our MDDB and the UDAS, we conducted training seminars in Indonesia and Austria in 2012, during which developers had the opportunity to visit the observatories, or during summer schools held in diverse locations, including some in developing countries. We held such seminars at the 208th Symposium on Sustainable Humanosphere Science School 2012 in Indonesia, UN data analysis symposium 2012 at Graz, Austria, and International Space Weather Initiative MAGnetic Data Acquisition System (MAGDAS) School 2012 (Figure 5). In addition to these face-to-face meetings, we held two online seminars in 2013 using

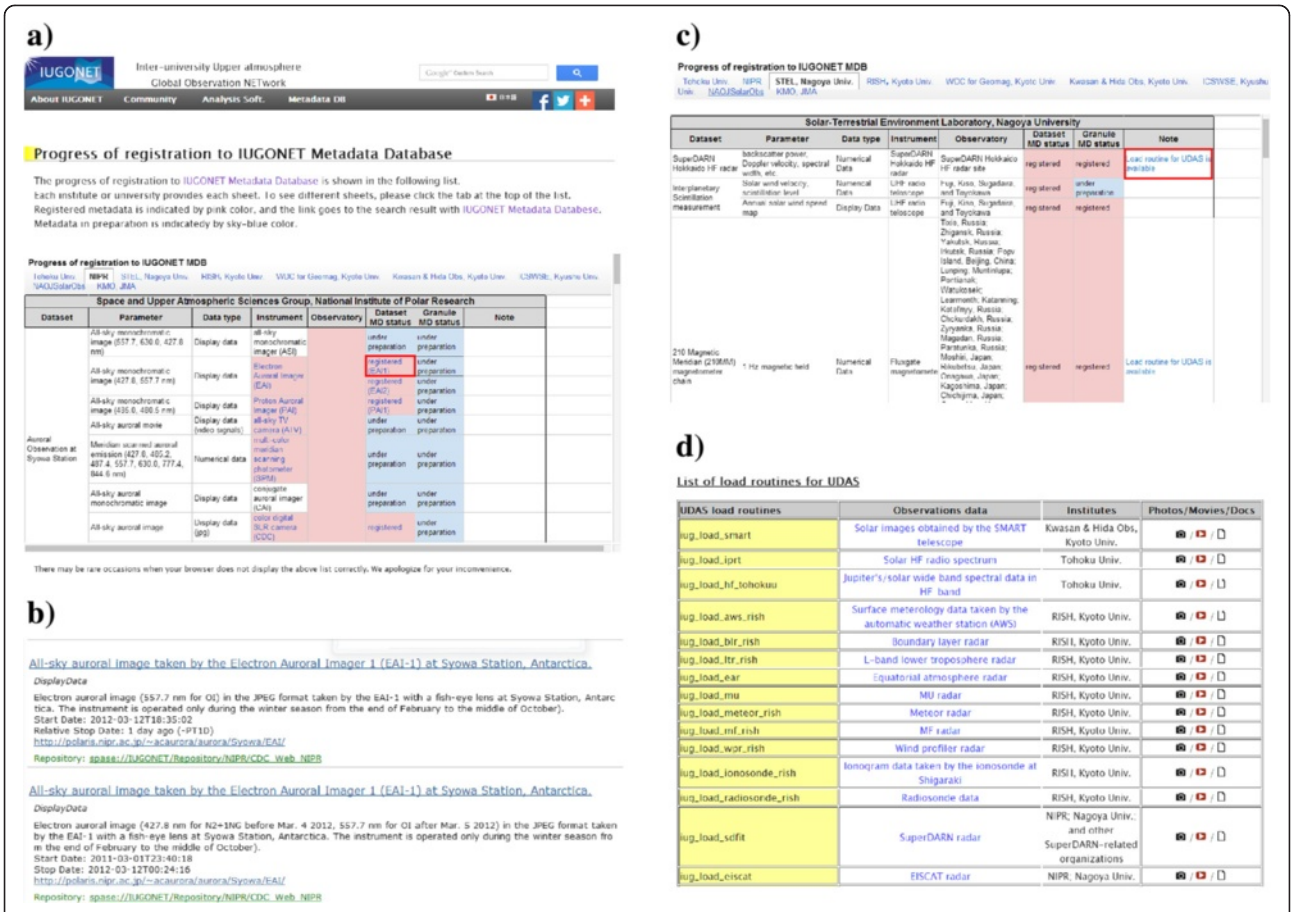

Figure 4 Example of the progress table of IUGONET MDDB (http://www.iugonet.org/en/mdblist.html). (a) Example of the National Institute of Polar Research. The pink (light blue)-colored cell means registered (under preparation). **(b)** Search results followed by clicking the red square in (a). **(c)** Example of the Solar-Terrestrial Environment Laboratory. Details are the same as in (a). **(d)** Available load procedure list (part) followed by clicking the red square in (c).

Internet conferencing systems, where many young scientists joined from Indonesia.

Science-enabling service of the IUGONET

As described above, about ten developers (researchers) are working exclusively for the IUGONET to build the MDDB/UDAS. In addition to the publication of technical papers on the development of the system, scientific papers using the IUGONET tools are included in the 'outcomes' of the project. Figure 6 summarizes the annual number of publications in the past 5 years; more than 90 papers have been issued annually. This includes IUGONET members' lead papers on observations that are registered in the IUGONET system (red, in Figure 6), and more than 60% of papers are published with ex-IUGONET researchers named as the lead author (green, in Figure 6). Additionally, papers on the IUGONET development activities (MDDB and software) have been issued (blue, in Figure 6), and a further 42 thesis papers (Bachelor, Master's and Doctoral) have been submitted up to March 2014.

Figure 5 Pictures of capacity-building seminars. (a) At Humanosphere Science School 2012 in Indonesia and **(b)** at United Nations data analysis symposium 2012 at Graz, Austria.

In addition to the abovementioned capacity-building international activities, the IUGONET has initiated international cooperation with a similar European database project, the Near-Earth Space Data Infrastructure for e-Science (ESPAS) (The ESPAS Consortium 2014), to construct an interoperable database. Together with the European and the US SPASE communities, we have

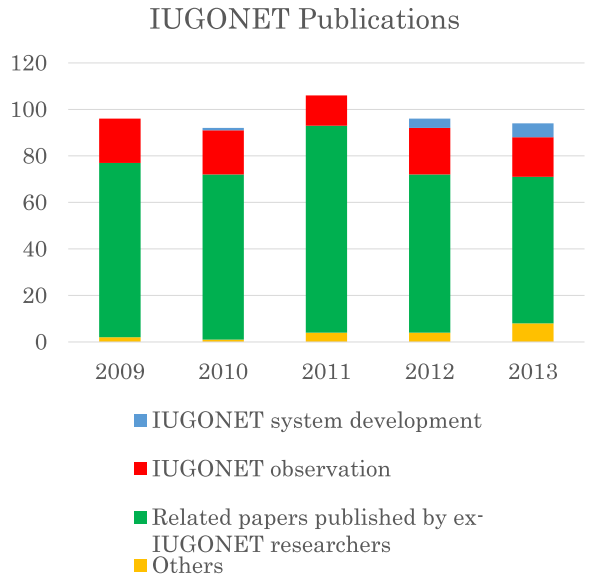

Figure 6 Year-to-year numbers of reviewed papers issued by the IUGONET activities. Blue designates the number of papers on the development of the IUGONET products, red designates papers on IUGONET-related observational data analyses, green shows papers written by non-IUGONET members as the first author, and yellow denotes the number of other category papers.

Table 1 Countries that are associated with IUGONET activities

Access to MDDB (top ten countries)	Mailing list	
Japan (approximately 80%)	Japan	126
US[a]	India[b]	8
Germany[a]	Indonesia[b]	5
Ukraine	Taiwan	3
Austria[b]	US[a]	3
India[b]	Australia	2
Indonesia[b]	China	2
Russia	Finland	2
France	Nigeria	2
China	Brazil	1
(Others)	Egypt	1
	Germany[a]	1
	Iraq	1
	Korea	1
	Malaysia	1
	Thailand	1

(Left) Top ten countries accessing the IUGONET MDDB. (Right) Nationalities of the participants in the IUGONET mailing list (as of 15 July 2014). [a]Countries cooperating in promoting research. [b]Countries that have received training seminars.

organized several sessions at international meetings, and because of both these international activities, the number of users of the IUGONET products is increasing.

Table 1 shows the countries that access the MDDB and the number of participants included in our mailing list according to their countries. In the 2 years since the release of the MDDB, about 80% of users have been from Japan, and the second and third highest users appear to be our cooperators associated with the SPASE and ESPAS communities. Among the other countries, our capacity-building activities in India, Indonesia, and Austria appear to have contributed to their greater access of our MDDB.

With regard to the mailing list that we started to compile in 2013, 85% of participants are from within Japan. However, the numbers of participants from India and Indonesia, where we have undertaken capacity-building activities, including domestic education to foreign students/PDs, are relatively high. Although the numbers are small, we do have participants from all continents and regions except Oceania (Asia, North/South America, Europe, Africa, and the Middle East).

Discussion

As described above, registration of the MD is performed by postdoctoral fellows and other members of the STP community. This provides both the users of the MDDB and the postdoctoral fellows with greater understanding of the data and of their systems of observation. In addition, the international outreach/capacity-building lecture activities provide good experience for both the students and the facilitator of the training seminar.

Although the UDAS is a powerful tool for acquiring, displaying, and analyzing data, the main software components differ considerably from those used by the science community at large. Therefore, the interoperability of such tools should be improved by using other suitable software, for example, that being used by the meteorological community.

The capacity-building activities of the IUGONET have been linked to the activities of several institutions, e.g., the MAGDAS School and the RISH/Kyoto University's Equatorial Atmosphere Radar site. These institutional capacity-building activities are performed independently under the CAWSES-II program (Ueno et al. 2013). However, we hope that in the future, the IUGONET will take a role in networking these capacity-building activities.

The IUGONET facilitates exchange of data information (MD) on the Internet. Because we carefully selected the international 'standard' of the format of the MD and general design of the analysis software, our tool can be linked easily with other research activities, e.g., satellite missions in the upper atmosphere and other databases such as the Solar-Terrestrial Data Analysis and Reference System (Murata et al. 2002; Kunitake et al. 2013). We believe that our long-term database will play an important role for the international scientific community. In particular, we have

contributed to the building of a database that enables users to search effectively and access the global database obtained through international cooperative projects such as the IGY and CAWSES. However, promoting the use of the IUGONET's tools will not succeed without international and open data exchange. We hope that the SCOSTEP and WDS will promote such exchange. It would be helpful for us if the SCOSTEP sets a general regulation regarding the opening of data, as do other international science communities, e.g., meteorology and hydrology, such as setting the maximum moratorium period to 1 or 2 years for data obtained by international scientific projects.

Conclusions

- The IUGONET is a Japanese project that aims to construct an online system to provide an MD database and analysis tool for upper atmospheric research. These have been released on our website (IUGONET 2014b).
- The usefulness of the IUGONET has been proven by the increasing number of domestic and international accesses to its website by researchers from a variety of disciplines. International collaborations between the IUGONET and other data networks, such as ESPAS and SPASE, are continuing to secure interoperability.
- The IUGONET is an excellent tool for educating students and young scientists in developing countries because of its well-documented database and instructive analysis tools.
- The IUGONET community has been contributing to SCOSTEP programs, and it will collaborate with SCOSTEP's new program, the 'Variability of the Sun and Its Terrestrial Impact,' not only in its scientific activities, but also in the establishment of E-infrastructure and capacity building.
- We welcome any kind of cooperation, including increasing the interoperability and MD exchange among the database development groups.

Availability and requirements

Project name: Inter-university Upper atmosphere Global Observation NETwork (IUGONET) project
Project home page: http://www.iugonet.org/en/
Operating system(s): Windows, Mac OS, Linux
Programming language: IDL (for full use of UDAS/SPEDAS including command line tools)
Other requirements: SPEDAS (for use of UDAS)
License: IDL license (for full use of UDAS)
Any restrictions to use by non-academics: Any IUGONET products are freely available from the home page with the exception of IDL license for full use of UDAS.

Additional files

Additional file 1: IUGONET_Observatory.KMZ. A KMZ file for Google Earth to show the locations of IUGONET observatories and each link to the metadata database.

Additional file 2: IUGONET_Instrument.KMZ. A KMZ file for Google Earth to show the location and parameters of IUGONET instruments and each link to the metadata database.

Abbreviations

CAWSES: Climate And Weather of the Sun-Earth System; CEDAR: Coupling, Energetics, and Dynamics of Atmospheric Regions; ESPAS: A European project titled the near-earth space data infrastructure for e-science; ICSU: International Council of Scientific Unions; IGY: International Geophysical Year; IUGONET: Inter-university Upper atmosphere Global Observation NETwork; KML: formerly Keyhole Markup Language; MAGDAS: MAGnetic Data Acquisition System; MD: metadata; MDDB: metadata database; NASA: National Aeronautics and Space Administration; NGDC: National Geophysical Data Center; NOAA: National Ocean and Atmosphere Administration; NSSDC: National Space Science Data Center; OMTI: Optical Mesosphere Thermosphere Imagers; SCOSTEP: Scientific Committee on Solar-Terrestrial Physics; SPASE: Space Physical Archive Search and Extract; STP: solar-terrestrial physics; SuperDARN: Super Dual Aurora Radar Network; UDAS: iUgonet Data Analysis Software; VarSITI: Variability of the Sun and Its Terrestrial Impact; VHO: Virtual Heliospheric Observatory; VMO: Virtual Magnetospheric Observatory; VSO: Virtual Solar Observatory; VxO: a Virtual Observatory; WDC: World Data Center; WDS: World Data System.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

The named authors contributed directly to the capacity-building activity of the IUGONET, and they are responsible for the documentation used in this paper. All authors read and approved the manuscript.

Authors' information

Except for the named authors, the IUGONET project team members as of 31 March 2014 are as follows (in alphabetical order within each institution): Masato Kagitani, Yasumasa Kasaba, Yuto Katoh, Atsushi Kumamoto, Hiroaki Misawa, Takahiro Obara, Takeshi Sakanoi, Naoki Terada, Fuminori Tsuchiya, Manabu Yagi (Tohoku University), Akira Kadokura, Hiroshi Miyaoka, Takuji Nakamura, Yasunobu Ogawa, Masaki Okada, Natsuo Sato, Yoshimasa Tanaka, Yoshihiro Tomikawa (National Institute of Polar Research), Ryoichi Fujii, Yoshizumi Miyoshi, Tatsuki Ogino, Yuichi Otsuka, Kazuo Shiokawa, Norio Umemura (Nagoya University), Jun-ichi Furumoto, Hiroyuki Hashiguchi, Toshihiko Iyemori, Naoki Kaneda, Yukinobu Koyama, Masahito Nosé, Kazunari Shibata, Masahiko Takeda, Hiroaki Toh, Toshitaka Tsuda, Masanori Yabuki, Mamoru Yamamoto (Kyoto University), Daisuke Ikeda, Kiyohumi Yumoto, and Akimasa Yoshikawa (Kyushu University).

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Author details

[1]Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan. [2]National Institute of Polar Research, 10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan. [3]Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan. [4]International Center for Space Weather Science and Education, Kyushu University, 6-10-1, Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan. [5]Kwasan and Hida Observatories, Graduate School of Science, Kyoto University, Kurabashira, Kamitakara-cho, Takayama, Gifu 506-1314, Japan.

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