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History of EISCAT – Part 6: the participation of Japan in the EISCAT Scientific Association

Nobuo Matuura[a,☆], **Ryoichi Fujii**[1], **and Satonori Nozawa**[2]

[1]Research Organization of Information and Systems, National Institute of Polar Research 10-3, Midori-cho, Tachikawa-shi, Tokyo 190-8581, Japan
[2]Institute for Space-Earth Environmental Research, Nagoya University, Furo-cho F3-3, Chikusa-ku, Nagoya 464-8601, Japan
[a]formerly at: Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho F3-3, Chikusa-ku, Nagoya 464-8601, Japan
[☆]retired

Correspondence: Ryoichi Fujii (eiscatfujii@gmail.com)

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Abstract. In Sect. 1, the original planning of Japanese Svalbard IS (incoherent scatter) radar with phased-array antennas is described. In 1988, this plan was proposed as one of the major projects for the forthcoming Solar–Terrestrial Environment Laboratory, Nagoya University, Japan, to be reorganized by the Research Institute of Atmospherics at Nagoya University. On the other hand, in 1989, UK scientists proposed a plan of polar cap radar with parabolic dish antennas in Longyearbyen to the EISCAT (European incoherent scatter) Council. In Sect. 2, the circumstances leading to Japan's participation in the EISCAT Scientific Association, with details of its processes with strong collaborations with Norwegian scientists and the EISCAT Scientific Association are described. In 1995, Japan participated EISCAT Scientific Association as the seventh member country with funds contributing to the second dish antenna of the EISCAT Svalbard Radar. In Sect. 3, a summary of the EISCAT-related achievement by Japanese scientists is described, where major interests are the lower thermosphere wind dynamics, the magnetosphere–ionosphere–thermosphere coupling, characteristics, and driving mechanisms of ion upflow, electrodynamics of current, electric field and particles, characteristics and production mechanisms of auroras, such as pulsating aurora, and aurora tomography. In Sect. 4, a summary of the scientific collaborations between Japan and Europe, particularly those between Japan and Norway, and hopes for the forthcoming EISCAT_3D and further collaboration with EISCAT community are described.

1 Original planning of Svalbard Incoherent Scatter Radar (SIR) in Japan

In the mid-1980s, the Ministry of Education, Science, Sports, and Culture (hereinafter abbreviated as MEXT) in Japan requested the reorganization of the Research Institute of Atmospherics at Nagoya University. The Research Institute of Atmospherics had been established in 1949, and it aimed to research atmospherics and related natural phenomena such as VLF (very low-frequency) electromagnetic waves. In 1987, soon after this request, Sachio Hayakawa, the president of Nagoya University, asked an academic community in Japan, the Society of Geomagnetism and Earth, Planetary, and Space Sciences, to discuss and make a plan for the institute's reorganization. The society appointed Takasi Oguti of the Geophysics Research Laboratory at the University of Tokyo to chair the reorganization committee, which then made a plan to reorganize the Research Institute of Atmospherics into the Solar–Terrestrial Environment Laboratory (STEL). The aim of the new laboratory was to study on the structure and dynamics of the solar–terrestrial system.

The committee, represented by Oguti, set up four scientific plans as its major projects of the forthcoming STEL, one of which was a project to construct a Svalbard Incoherent Scatter Radar (hereinafter abbreviated as SIR) on its own. The motivation behind this project came from the fact that Svalbard was located statistically beneath the cusp, where solar wind plasmas and energy directly entered the magnetosphere, and hence, it was one of the key regions for the solar wind–magnetosphere–ionosphere interactions. A great advantage of Svalbard was that it was the only place beneath the cusp on the globe to have dark-sky time in the midday during winter, which made it possible to observe cusp auroras. In order to prepare the SIR project, Oguti asked Nobuo Matuura of the Communication Research Laboratory for the Ministry of Posts and Telecommunications to join the STEL in 1988. Since then, Matuura has been in charge of the SIR project, together with Satonori Nozawa (since 1989) and Ryoichi Fujii (since 1992). The outline of the SIR was that the SIR would be a bistatic incoherent scatter (IS) radar system with a transmitter/receiver dish antenna in Longyearbyen and a phased-array, multiple-beams receiving antenna in Ny-Ålesund, as shown in Fig. 1 (Matuura and Nozawa, 1991). The phased-array radar was designed also to have the capability to transmit radar beams and to work as a monostatic radar. The planned radar frequency was 400–500 MHz, and the peak powers of the transmitters were 3 MW for the dish antenna MSDC (multistage depressed collector) klystrons and TV klystrons and 3–5 MW for the phased-array antenna, with 3000–5000 crossed dipoles (solid-state module; 1 kW each), respectively, as shown in Fig. 2 (Matuura et al., 1990). It is noted that Kyoto University had successfully developed and installed a phased-array IS radar system called the Middle and Upper Atmosphere (MU) Radar (Fukao et al., 1985a, b) at Shigaraki in Japan during the Middle Atmosphere Program (MAP, 1982–1985), and they had been running it and obtaining noble, important atmospheric data that could not have been obtained before.

In September 1988, Oguti, who later became the first director of the STEL, visited Asgeir Brekke and his colleagues at the Auroral Observatory of the University of Tromsø and asked the Norwegian scientists to collaborate with Japan for the SIR project that would be independent of the EISCAT (European incoherent scatter) Scientific Association. On the other hand, the UK report, *The Polar Cap Radar*, signed by A. P. van Eyken, E. C. Thomas, P. J. S. Williams, and D. M. Willis proposed three parabolic dish antennas to be envisaged in Longyearbyen. The proposal was well received by the EISCAT Council (Asgeir Brekke, personal communication, 2011). A detailed investigation of the scientific and technical case for a polar cap radar was made already by 1990 (Cowley et al., 1990). In September 1989, at an EISCAT meeting at Hamburg, Germany which Matuura attended, a decision was made to examine the polar cap radar and consider the possible collaboration with the Japanese SIR group. We later learned that the EISCAT community was then skeptical of the technical feasibility of the Japanese SIR project with the phased-array system. It might be interesting to note that the

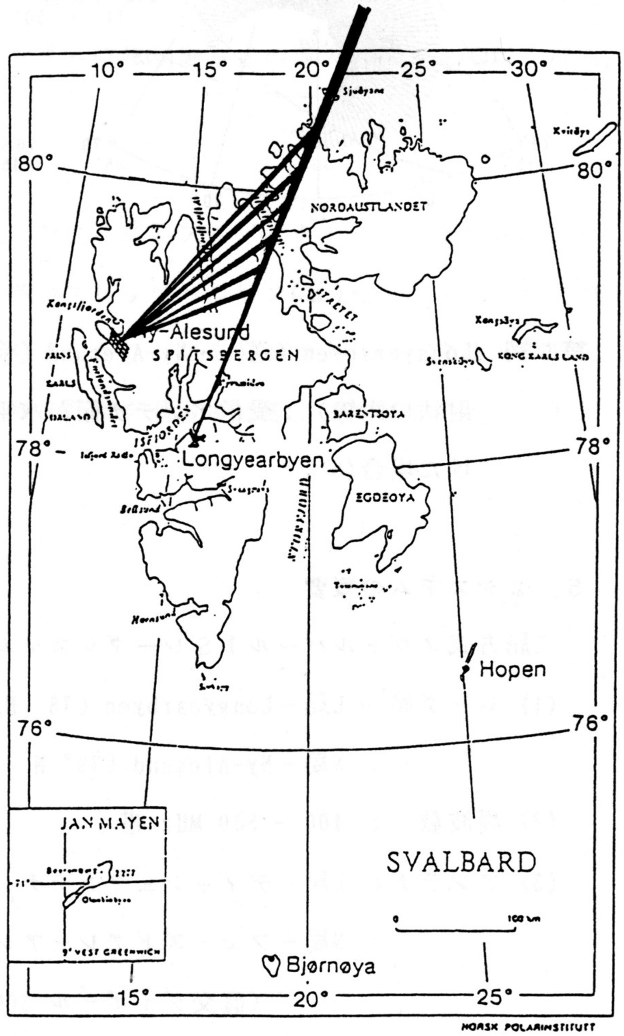

Figure 1. Bistatic Svalbard IS Radar (SIR) system planned originally by STEL (Matuura and Nozawa, 1991).

USA research group represented by the Geophysical Institute of the University of Alaska considered a plan to install phased-array IS radar systems at Poker Flat in Alaska and Resolute Bay in Canada and asked the Japanese SIR group to join their project at about that time. But that proposed collaboration was not considered further, especially after the proposal of the polar cap radar to the EISCAT community. The Japanese SIR project was thereafter discussed as a possible international project between the STEL and the EISCAT Scientific Association. The Polar Cap Radar Working Group was established by the EISCAT Council on 11 May 1990. Their report on the EISCAT Svalbard Radar (ESR) has 130 pages and lists the seven members of the group (https://eiscat.se/wp-content/uploads/2016/11/1991.pdf, last access: 9 November 1990). It was submitted to the council in August 1991. In this report, there was no trace yet of the interest in Japan joining the EISCAT Scientific Association,

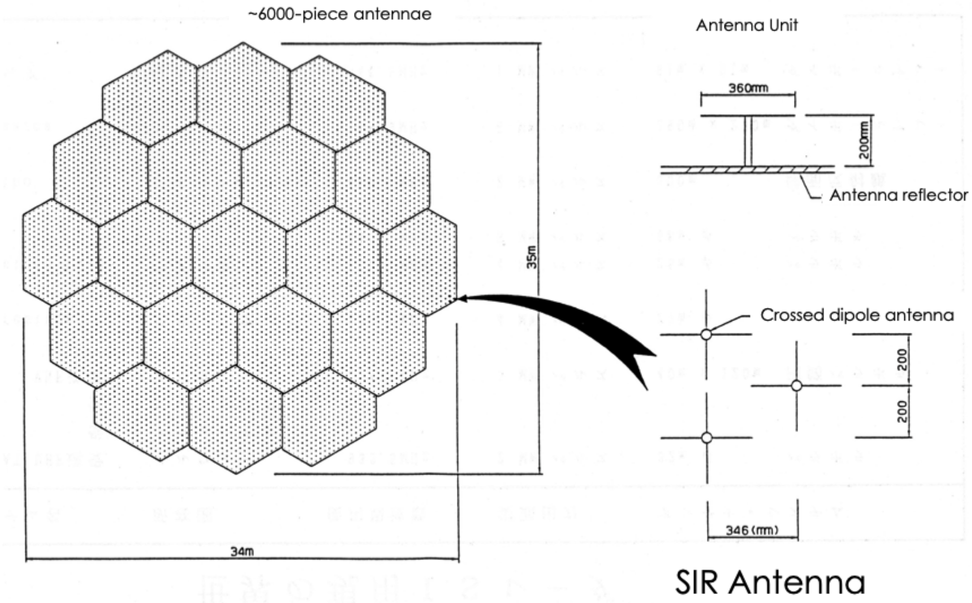

Figure 2. The structure of the SIR phased-array antennae (Matuura et al., 1990).

although this was already an on-going activity. The proposal was formally approved by the EISCAT Council at Uppsala, Sweden, in November 1992.

In June 1990, the STEL was established, and Oguti was appointed as the first director. The laboratory consisted of four research divisions, namely Atmospheric Environment, Ionospheric and Magnetospheric Environment, Heliospheric Environment, and Integrated Studies. The division of the Ionospheric and Magnetospheric Environment was in charge of the SIR. A unique characteristic of the laboratory was the function of the interuniversity collaboration that promoted joint research projects for research institutions and researchers nationwide. The laboratory was again reorganized in 2015 and named the Institute for Space–Earth Environmental Research, which has further expanded its function to clarify the mechanisms and relationships between the Earth, the Sun, and cosmic space, treating them as a seamless system. In December 1990, one of the four major projects of STEL, the SIR project, was proposed (Matuura and Oguti, 1991). In April 1991, at the general assembly of the European Geophysical Society in Wiesbaden, Germany, at the request of the EISCAT group, Matuura, on behalf of STEL, presented the SIR project of a phased-array antenna system at Longyearbyen. The EISCAT group presented their polar cap radar project of the dish antennae system at Longyearbyen. The difference between the two systems with their comparison was reported in *Nature News* (Aldhous and Swinbanks, 1991).

2 Japan's participation in the EISCAT Scientific Association with the construction of the second Svalbard IS antenna

In August 1992, Oguti and Fujii visited the place of the candidate site of SIR, Ny-Ålesund, accompanied by Brekke and Truls Hansen. At that time, the STEL still pursued the independent SIR project. After having carefully observed the site, Oguti and Fujii realized various difficulties in the construction and running of SIR, e.g., rather severe regulation to reduce any impact on the natural environment that would certainly make the construction of the active antenna difficult. The following intensive discussion with Brekke can be marked as the point at which Japan seriously started to consider cooperating with the EISCAT Scientific Association instead of trying to realize its own independent SIR initiative at Svalbard. On the very next day, Oguti told Brekke and the dean of the University of Tromsø to incorporate Japan's project into the EISCAT proposal. Indeed, in November 1992, Matuura, on behalf of STEL, informed Brekke with an official letter that STEL was thinking of changing its future proposal so that Japan would primarily participate in the EISCAT Longyearbyen radar plan, with a Japanese in-kind contribution to the construction of the second parabolic antenna dish. We later learned that there had been some skepticism within the EISCAT community about how the EISCAT membership could be technically expanded outside Europe. Actually, there were various practical difficulties for Japan's participation in the EISCAT Scientific Association, such as how to make large investments in foreign countries while retaining ownership, continuous financing through different fiscal years, etc.

We were very fortunate to have two key persons helping us solve those difficulties during the period of the planning and negotiation with the EISCAT Scientific Association. These two persons were Brekke and Jürgen Röttger, the director of the EISCAT Scientific Association at the time. Without their devoted efforts and without their help, it would never have been possible at all for Japan to join the EISCAT Scientific Association. One of the two, Brekke, continuously acted in a central role in the collaboration between Japan and the EISCAT community before and during his vice-presidency and presidency of the EISCAT Council. Brekke often visited Japan, stayed at STEL three times as a visiting professor, and tried to persuade MEXT and Nagoya University that the Japan's participation would inevitably require a rather large budget at the beginning and stable annual membership fees later. He invited Nozawa to the University of Tromsø for 10 months in 1992 and gave him opportunities for training in the operation of the EISCAT radars and to process/-analyze EISCAT data that were essentially important for the later development of the EISCAT user community in Japan. In 1993, Brekke was elected the chairperson of the EISCAT Council, and he accelerated the process for the Japanese participation in the EISCAT Scientific Association. During the general assembly of the International Union of Radio Science (URSI), which was held at the end of August 1993 in Kyoto, Japan, an exhibition stand titled "ESR–International Collaboration" was prepared by the STEL of Nagoya University and the EISCAT Scientific Association (The EISCAT Annual Report 1993, https://eiscat.se/wp-content/uploads/2016/06/1993-Annual-Report-scanned.pdf, last access: 21 April 2023). After the URSI General Assembly in September 1993, the EISCAT delegation consisted of Brekke and Röttger, and Jorma Kangas of the University of Oulu, Finland, visited Nobuo Kato, the president of Nagoya University and encouraged him to apply for membership in the EISCAT Scientific Association on behalf of Japan. Following this meeting, they also visited Masayuki Inoue, the director of the Division for International Research at MEXT, and again encouraged him to support the application of Japan becoming a member of EISCAT, stating that EISCAT was considering Japan as a welcomed collaborator, and the EISCAT was ready to invite Japan to participate in the EISCAT Council.

In June 1994, STEL asked Masahiro Nishio, the director general of Nagoya University, to visit Svalbard for an inspection tour of EISCAT. This tour convinced him of the importance of participating in the EISCAT Scientific Association for Japan and Japanese researchers. After returning to Japan, he immediately started to negotiate with MEXT for the Japan's participation in the EISCAT Svalbard Radar project, which we think triggered the merging of the two projects and Japan becoming an associate of the EISCAT Scientific Association. In late August to early September 1994, the Japan EISCAT Symposium on the Polar Ionosphere was held in Toba, Japan, with co-sponsorship by STEL and the EISCAT Scientific Association. It was very successful in terms of the shard scientific values and personal ties formed between European and Japanese scientists, with 61 scientists in attendance, including 17 scientists from foreign EISCAT-related countries. Among participants were Keisuke Yoshio, a high governmental official from the Division for International Research at the MEXT and Hiroyuki Ito, the director general of Nagoya University. Through this participation, we had a hunch that the STEL's proposal would be approved and funded. Some of the papers submitted to the Symposium were published in the *Journal of Geomagnetism and Geoelectricity* in Japan (Matuura and Kamide, 1995). After the symposium, Brekke, Eivid Thrane of the Norwegian Defence Research Establishment, and Röttger, together with Susumu Kokubun, the director of STEL at that time, and Matuura visited Inoue at MEXT again. Inoue informed them that the MEXT instead of Nagoya University was going to fund the Japanese EISCAT project to the National Institute of Polar Research (NIPR). This was probably because the NIPR has been in charge of promoting scientific activities, particularly large research projects of Japan, in both of the Arctic and Antarctic regions.

In May 1995, funds for the Japan's participation with the in-kind contribution to the second dish antenna were released by MEXT. The EISCAT Council approved Japan's participation in the EISCAT Scientific Association as the seventh associate country at the Council Meeting held in Hamburg, Germany, on 23 May 1995, which concluded with the Memorandum of Understanding between the National Institute of Polar Research (signed by the director general Takeo Hirasawa, NIPR) and the EISCAT Scientific Association (signed by Director Jürgen Röttger). At the same time, the EISCAT Agreement among the original six associate countries ended, and the new agreement was signed by the seven associate countries, including Japan. Delegates and executives of the Council Meeting are seen in the photo (Plate 1). The first inauguration of the EISCAT Svalbard Radar group was held on 22 August 1996 at the radar site in Longyearbyen. Tadayuki Nonoyama, the Japanese ambassador in Norway, and a delegation from Japan (Plate 2) attended the inauguration ceremony.

This is a major outline of the Japan's participation in the EISCAT Scientific Association. There were, however, certain subjects between Japan and the EISCAT Scientific Association that had to be carefully and comprehensively deliberated, treated, and prepared and in which Röttger, director of the EISCAT Scientific Association, played an essential and indispensable role. The deputy director, Anthony P. van Eyken, also helped the process very much, particularly with respect to the scientific aspects. As mentioned earlier, the EISCAT Council was sometimes skeptical about Japan's participation in the EISCAT Scientific Association as an associate country, probably since this was the first case of a new member for EISCAT and, furthermore, the participation of a non-European country. Röttger moved important issues forward with strong leadership, while always respecting the

Plate 1. Japanese delegation, EISCAT Council delegates, and executives at the council meeting on 23 May 1995 in Hamburg, Germany (Hirasawa, director of NIPR, in the center of the first row, Brekke on the right, Röttger fourth from left, Fujii, and Kokubun on the left).

Plate 2. Japanese delegation at the inauguration of the EISCAT Svalbard Radar on 22 August 1996 in Longyearbyen (Matuura on the far right, Hirasawa, director general of NIPR, on the second right, and Kokubun, director of STEL, on the second left).

authority, opinions, and orders of the EISCAT Council. The issues were, for example, preparations for how to deal with a new associate, Japan, in the agreement (i.e., concerning the in-kind contribution for the joining EISCAT and the rights of Japan, such as the allocation method of the observation time for Japan on the in-kind and annual contributions, etc.). He did, with careful and well-thought-out strategies, his best to provide both the EISCAT Council and Japan with acceptable, possible proposals, after having carefully observed and examined both parties.

Plate 3. The second dish antenna of the EISCAT Svalbard Radar taken on the occasion of the inauguration in May 2000.

Röttger and his colleagues at the EISCAT headquarters in Kiruna, Sweden, intensely supported us in technical and financial subjects such as, e.g., the construction of the second antenna. Soon after the intention of the MEXT to fund the second antenna was dispatched from Inoue in September 1994 after the EISCAT delegation had visited him, STEL and NIPR started an investigation of the antenna and contacted Kvaener Kamfab Ab, which had constructed the first Svalbard IS antenna, in order to collect necessary information. The category of the MEXT budget for the second antenna, however, had a difficult restriction in that the budget had to be used in principle within 1 year, at most in 2 years, although construction work in Svalbard could be made only for in a short period around summer. It was clear that 2 years were too short to complete the antenna construction, before and after the MEXT's release of the funds for the second dish antenna in May 1995, under such difficult circumstances. Röttger and his colleagues at the EISCAT headquarters helped us very intensively, and finally, the second antenna was installed in due time in 1999. The second antenna of the EISCAT Svalbard Radar was constructed by a French company, Alcatel, which was selected in 1998, and came into operation in 1999. The inauguration of the second antenna was held in May 2000 (Plate 3).

3 EISCAT-related achievement by Japanese scientists

The Japan's participation made the EISCAT community more global, and Japan has established a trustworthy position in the EISCAT Scientific Association, in close collaboration with the EISCAT associate countries. The activity of the EISCAT research community in Japan hosted by NIPR and STEL has been growing year by year. Nationwide, researchers and graduate students have been enjoying the radar experiments at Ramfjordmoen and in Longyearbyen (http://polaris.nipr.ac.jp/~eiscat/en/, last access: 21 April 2023). Furthermore, we have been conducting more comprehensive and coordinated projects, together with simultaneous ground-based and space-borne observations in close collaboration with the EISCAT community, where in most cases the central sites of the projects have been located at Ramfjordmoen and in Longyearbyen. For example, the Pulsating Aurora (PsA) project, with three stations in northern Scandinavia, has been conducted since 2015 (http://www.psa-research.org/english/, last access: 21 April 2023).

Japanese scientists have conducted research with EISCAT in a variety of science themes, including the lower thermosphere wind dynamics considering energy and momentum inputs from below and above, the magnetosphere–ionosphere–thermosphere coupling, characteristics and driving mechanisms of ion upflow, electrodynamics of current, electric field and particles associated with substorms, characteristics and production mechanisms of auroras, such as pulsating aurora and patch aurora, and aurora tomography. Some of the scientific achievements obtained from this research are briefly described in the following.

Nozawa and Brekke (1995) showed that the diurnal amplitude of neutral wind enhanced by a factor of 3 between quiet and disturbed days, and Nozawa and Brekke (1999a, b) showed the seasonal and solar cycle variations in the mean, diurnal, and semidiurnal components of the neutral wind between 95 and 120 km in the lower thermosphere. Fujii et al. (1998) showed that the neutral wind mechanical energy transfer rate is comparable to the Joule heating rate in the lower thermosphere. Based on the simultaneous ESR and VHF radar, Ogawa et al. (2000) showed that field-aligned ion upflow observed at 665 km in the dayside cusp was associated with significant anisotropy of ion temperature, isotropic increases in electron temperature, and enhancements of electron density. Ogawa et al. (2010) further found that the upward ion flux is generally high when solar activity is high than it is low. Fujii et al. (2012) proposed a new physical process for the latitudinal motion of an auroral arc based on the four-side bound Cowling channel model. Hosokawa et al. (2016) visualized, for the first time, how the gradient drift instability (GDI) stirs the patch plasma and that such a mixing process makes the trailing edge more gradual. Miyoshi et al. (2015), using simultaneous Arase satellite and ground-based observations, revealed that electrons with a wide energy range simultaneously precipitate into the ionosphere in association with the pulsating aurora, providing evidence that pulsating auroras are caused by whistler chorus waves. Fukizawa et al. (2022), using aurora observation networks during the PsA project in northern Scandinavia showed that the horizontal distribution of precipitating electrons associated with PsAs could be effectively reconstructed from ground-based optical observations. Based on long-term variations in plasma temperatures in the polar thermosphere, Ogawa et al. (2014) have made a study of the upper atmosphere cooling based on 33 years of EISCAT data. Furthermore, Japanese scientists have, so far, launched eight Japanese rockets from the Andøya Rocket Range (now called the Andøya Space Center) or Ny-Ålesund. Using the coordinated observational data during one of these Japanese rocket experiments, the DELTA (Dynamics and Energetics of the Lower Thermosphere in Aurora) rocket campaign (Abe et al., 2006; Nozawa et al., 2006), Kurihara et al. (2009) indicated that large vertical winds must be responsible for the fast response of the vertical wind to a heating event.

It is noted that, under collaborations with the University of Tromsø (UiT), Japanese scientists have operated/installed a variety of instruments for comprehensive and coordinated observations, such as photometers (Adachi et al., 2017; Nozawa et al., 2018), MF (medium frequency) radar (Nozawa et al., 2003), meteor (MR) radar (Hall et al., 2005), sodium lidar (Nozawa et al., 2014), EMCCD TV cameras (Hosokawa et al., 2023), digital camera (Nanjo et al., 2022), FPI (Fabry–Pérot interferometer; Shiokawa et al., 2012), and all-sky imagers (Ogawa et al., 2020) at Ramfjordmoen. The two meteor radars at Tromsø and Alta, where Japanese scientists are co-owners, are part of Nordic Meteor Radar Cluster (Stober et al., 2021). These instruments have been widely used together with EISCAT radars to understand auroral and polar sciences mentioned above.

The number of published and peer-reviewed journal papers related to EISCAT by Japanese scientists is 240 (160 by Japanese first authors) as of 2021.

4 Concluding remarks

In total, 27 years have passed since Japan's participation and 34 years since the first contact of Oguti with Brekke. It may be worth mentioning that the Japanese EISCAT activity has been ranked as an important component of the very long-term collaborations between Japan and Europe, particularly with Norway. Historically, Kristian Birkeland stayed in Tokyo and died there in 1917, and Japan was one of the 14 original signing countries of the Svalbard Treaty in 1920. The recent collaboration started on the mainland of Norway in the 1970s between Oguti, the University of Tokyo, and Alv Egeland, the University of Oslo, for ground-based observations with magnetometers. The collaborations in Svalbard started in 1985 for ground-based observations with magnetometers and scanning riometers at Ny-Ålesund. Observations/measurements with rockets and balloons had also started well before Japan's participation in the EISCAT Scientific Association. The coordinated network ground-based observations with a variety of instruments mentioned in Sect. 3 have been conducted on the mainland of Norway and in Svalbard and in Sweden and Finland. Furthermore, data retrieval from a Japanese Sun observation satellite, Hinode, took place at Longyearbyen. The observation projects after 2010 in Svalbard have also been involved in the Svalbard In-

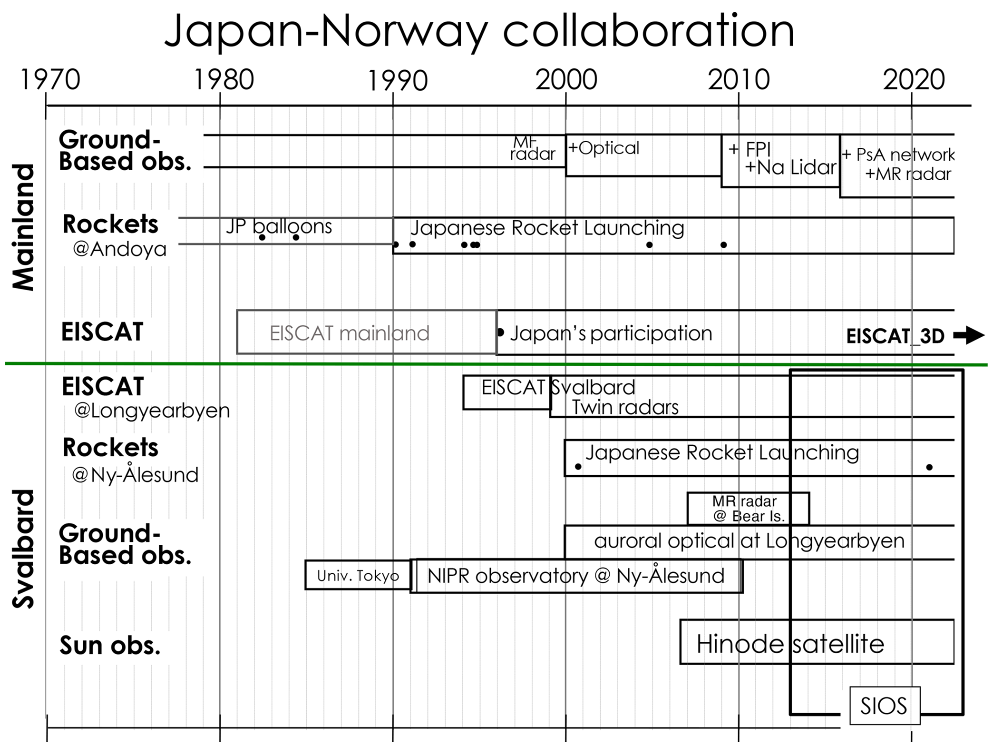

Figure 3. History of the Japan–Norway/Europe collaborations in space science.

tegrated Arctic Earth Observing System (SIOS). This wide range of recent observation activities with ground-based instruments (mentioned in Sect. 3) and with eight rockets and the Hinode satellite under international collaboration, along with the EISCAT mainland and Svalbard radar programs, are summarized in Fig. 3. We wonder whether the experience and trust between Japan and Norway that has been earned through these activities lead to STEL's plan for a Svalbard IS Radar project and to the later joining of the EISCAT Scientific Association by Japan. Now the EISCAT_3D (McCrea et al., 2015), whose fast time sampling capability actually makes it 4D, is expected to provide us with new, astonishing information and insights of the space around the Earth that no one has ever seen before. The Japanese EISCAT community has been making extensive preparations for the EISCAT_3D being constructed and has been expanding on the ground-based observations with great excitement.

Data availability. No data sets were used in this article.

Author contributions. NM was in charge of all of the content of the paper and, in particular, was responsible for the section of the history of Japan's own IS radar program. RF was in charge of the section regarding collaborating and negotiating with EISCAT and also within Japan. SN was in charge of the section of the Japanese scientific activities and achievements associated with EISCAT.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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