Japanese history of space weather research and Operation

Mamoru Ishii[1], Osamu Takizawa[1], Katsuhide Marubashi[2], and Mitsue Den[1]

[1]National Institute of Information and Communications Technology
[2]Unknown

November 23, 2022

Abstract

Japanese space weather research and operation began in 1896 with research on radio propagation. LF, MF, and HF radio communication used to be important before the era of communication satellites; however, they are affected by ionospheric conditions and solar activity. A center for the research and development of radio systems was established at Hiraiso, which is now also a space weather observatory for measuring solar activity, geomagnetic fields, and ionospheric conditions. The need for space weather information initially decreased in the communication satellite age, but since the beginning of the 21st century it has been increasing again with the growing use of positioning satellite systems. The role of Southeast Asian countries in space weather research has become important and the range of activities is also growing. The contribution of these countries to space weather research and operation is expected to grow in future.

Japanese history of space weather research and Operation

M. Ishii, O. Takizawa, K. Marubashi, and M. Den

National Institute of Information and Communications Technology

Corresponding author: Mamoru Ishii (mishii@nict.go.jp)

Key Points:

- The origin of Japanese space weather forecast began in 1896 with radio propagation research.
- Global space weather research and operation are now widespread.
- The importance of Southeast Asian countries in space weather research and operation will increase significantly with the increasing use of GNSS and its applied technologies.

Abstract

Japanese space weather research and operation began in 1896 with research on radio propagation. LF, MF, and HF radio communication used to be important before the era of communication satellites; however, they are affected by ionospheric conditions and solar activity. A center for the research and development of radio systems was established at Hiraiso, which is now also a space weather observatory for measuring solar activity, geomagnetic fields, and ionospheric conditions. The need for space weather information initially decreased in the communication satellite age, but since the beginning of the 21st century it has been increasing again with the growing use of positioning satellite systems. The role of Southeast Asian countries in space weather research has become important and the range of activities is also growing. The contribution of these countries to space weather research and operation is expected to grow in future.

1 Introduction

Space weather is defined as variations in the space environment in the vicinity of the Sun and Earth that affect human activities. Extreme space weather impacts on various fields of human activities, e.g., telecommunications, satellite positioning, electric power grids, satellite operations, and aviation.

There are several organizations providing space weather information operationally in addition to academic institutes and universities. These operational space weather information providers have various origins because various fields of human activities are influenced by space weather phenomena. The mother bodies include meteorology agencies, space agency radio research institutes, and natural resource institutes.

In Japan, the initial motivation for monitoring space weather was to monitor HF wave propagation for telecommunication. We review the history of Japanese space weather operational activity in the next section.

The largest space weather event on the record is named the Carrington Event, which occurred in September 1859, during which wired telegraph systems in the UK burned owing to large geomagnetically induced currents, and very bright auroras appeared. Our society has since developed advanced information and communications technology, raising concern about the large impact of extreme space weather. Some studies (e.g., Oughton et al., 2017, 2019) have estimated the daily economic impact of extreme space weather, especially due to the failure of electric power supplies. The social impact would be largest in high-latitude countries, mainly due to the shutdown of the electric power grid, and the economic impact of an extreme event in high-latitude countries would be equivalent to that of the Tohoku earthquake in Japan in March 2011.

Space weather disasters are rare but when they happen, the impact could have national or globalimplications. Section 3 introduces some major activities carried out by national and multinational organizations in preparation for extreme space weather events, in which the role of Southeast Asia is becoming increasingly important.

2 History of Space Weather Research and Operation in Japan

2.1 Dawn of Japanese wireless telecommunication

The first institute to carry out operational research and development on wireless telecommunication in Japan was established in October 1896, which was the Radio Telegraph Research Division of the Electrotechnical Laboratory, Ministry of Communications. This was very soon after the first successful radio communication by Guglielmo Marconi in 1895.

The first operational radio communication in Japan was used in a sea battle of the Russo-Japanese War in 1904, during which the message, “Today the weather is clear but the ocean is rough” was communicated from the battleship *Mikasa*. The advantage of communication helped Japan to defeat Russia, which had the strongest navy in the world at that time. This victory convinced the imperial government of Japan of the importance of telecommunication, and they established the Hiraiso branch of the Electrotechnical Laboratory in January 1915. The site has a wide test field and was convenient for experiments on long distance wireless telecommunications, especially for trans-Pacific communication with the US. The Hiraiso branch gave rise to various major Japanese telecommunication institutes and companies, such as AIST, NICT, NTT, and KDDI, after World War II.

The history of the Hiraiso branch has three phases: (1) 1915 to the 1930s – the era in which new hardware and systems were developed and utilized, (2) the 1930s to the 1980s – the era in which the field of research expanded to the ionosphere and solar terrestrial physics to develop and improve radio alerts necessary for radio telecommunication, and (3) the 1980s to 2018 – the era of research and development on space weather forecast systems.

The Hiraiso branch produced some groundbreaking results during the first phase. Uichi Torikata, Eitaro Yokoyama, and Masajiro Kitamura developed the world’s first full-duplex radiotelephone in May 1917. They had begun to develop a practical radiotelephone named the “TYK type,” taken from their initials, in 1912, which was in operation from December 1914 to communicate between Toba and Kamishima, both in Mie prefecture (Okamura, 1994) They improved the system by using a vacuum tube and started to use it in operations on May 12, 1917. This was the first operational use of a radiotelephone with a vacuum tube for public telecommunication in Japan.

In those days, the transmitter and receiver were physically separate in a full duplex long-distance radio telegraph system so that the transmitting signal did not interfere with the receiver. However, it was impossible to use this scheme in a radiotelephone and the users applied pless talk or half-duplex communication. The development of a radiophone system with a vacuum tube improved systems for full-duplex communication. The Hiraiso branch began to study the use of radio waves with two different frequencies with one transmitter and one receiver antenna. They carried out a successful experiment to communicate between two points 32 miles apart with this full-duplex radiophone in July 1917. This allowed them to connect wired and radiophone systems. They also successfully exchanged messages between a wired telephone in Tokyo and a radiophone in a ship off the coast near Shinagawa in October 1917, two years ahead of other countries.

In 1910, G. O. Squier advocated the concept of carrier telephony to transmit multiple signals with different frequencies using a single wire in 1910. The Hiraiso branch developed such a system from 1917 to 1920 and used it to communicate between an electric power plant and a transformer substation.ref

The Hiraiso branch achieved some significant results in the development of radio broadcasting. Radio broadcasts started in the US in the 1920s. In Japan, many studies on MF radio broadcasting were carried out around 1924, such as a quantitative survey of the relationship between the electric field and the radiation height of an antenna, the shielding of interference, and the development of a superheterodyne receiver. Figure 1 is a photograph taken during an experiment on receiving a signal from the US KGO station in August 1924. Mr. Noboru Marumo, the second director of the Hiraiso branch (center) tried to receive the signal and Mr. Eijiro Takagishi, the third director (left), assisted in the experiment (Okamura, 1994, Shiomi and Hatori, 2000).

On August 30, 1924, the Hiraiso branch succeeded in receiving a radio broadcast from the US for the first time in Japan. At this time, a radio broadcast station of GE Company in Orkland, US had a special campaign to transmit radio broadcasts to Japan with a power of 3kW and a frequency of 962kHz. On the basis of these groundbreaking results, Japan started operational MF radio broadcast in Tokyo (JOAK) on March 22, 1925.

The main research of the Hiraiso branch moved from MF use to HF use around 1925. Radio institutes all over the world including the Hiraiso branch carried out a survey on receiving HF test signals. In addition, the Hiraiso branch established an experimental radio station with a newly developed HF transmitter on 1925 with a call sign of “JHBB” and a call name of “Hiraiso experimental station.” The station began transmission with a power of 300W and a wavelength of 25m to survey radio propagation over short distances. Figure 2 shows the HF radio communication system developed at Hiraiso around 1925. Figure 2(a) shows a transmitter and Figure 2(b) shows a talking room, which used a double-bottom microphone made by Western Electric Company of the US.

In the same period, the Hiraiso branch started to develop an HF radio transmitter, which was completed in 1928, and they carried out continuous transmission experiments as one of the pioneers of international broadcasting.

2.2 Monitoring the ionosphere for radio telecommunication

The Hiraiso branch focused on the development of a radio telecommunication system in its first 10 years after it was established. Through the accumulation of experimental results, it was revealed that radio propagation has diurnal and seasonal variations and is influenced by conditions in space. In the same period, Appleton discovered the existence of two regions in the ionosphere (the E and F regions), (e.g., Rishbeth (1994)) which triggered a shift in the research in the Hiraiso branch toward monitoring the ionosphere. One of the results of this research was a “world maps of F2 critical frequencies and maximum usable frequencies for 4,000 km” published in 1958, which provides a practical method of calculating the electric field strength of HF communication between any two points on the Earth’s surface as function of the season, time, and wavelength (Nishida, 2010). This map was used not only in Japan but also worldwide, and was also adopted for LF and MF communication. The method of calculating HF propagation was improved by including the injection angle.

In 1932, the Hiraiso branch started preparing for the direct observation of the ionosphere using a pulse injection method with a fixed frequency. From March to September 1933, they attempted to perform temporal ionospheric measurement while transmitting radio waves to Oyama station, 75km west of Hiraiso. From 1934, the Hiraiso branch observed the ionosphere continuously between Hiraiso (Tx) and the Isohama annex (Rx) while manually changing the frequency to measure the critical frequency of the E region once a day at noon. Figure 3 shows the ionosonde system in use around 1934–1935. Figure 3(a) shows the transmitter installed in Hiraiso and Figure 3(b) shows the receiver installed in the Isohama annex. In addition, they started ionospheric observation in 1936 by sweeping the frequency to measure virtual height once in a week. They improved the automatic observation system and revealed the fine structure of the ionosphere, HF propagation mechanisms, and the solar effect on propagation through observation during a solar eclipse.

In those days, some research on VHF propagation was also carried out in the Hiraiso branch. It was known that fading occurred in VHF telecommunication between Tx and Rx, which were about 100km apart, but they were unable to find the reason for this. They carried out experiments in which 45MHz VHF waves were sent from Tokyo to Hiraiso, 110km northeast of Tokyo, which were successfully received at Hiraiso. This survey contributed to the subsequent development of TV broadcast services.

The Hiraiso branch also carried out research on direction finding and radio beacons for the safe transport of ships and aircraft from 1929. These studies led to the development of radar, first used in WWII.

2.3 Space weather monitoring

When Japan entered WWII in 1941, the Hiraiso branch stopped operational ionospheric observations and focused on the improvement of radars.

After WWII, Japanese institutes for radio science and research were merged and restructured several times. The Radio Research Laboratory (RRL) was established on August 1, 1952, and the Hiraiso branch became Hiraiso Radio Observatory (hereafter Hiraiso observatory) as part of RRL.

The focus of Hiraiso observatory also changed to radio alerts, i.e., the forecast and dissemination of anomalous radio propagation. For this task, Hiraiso observatory began to monitor not only the ionosphere but also the geomagnetic field, ground current, and solar activity. The radio alert service at Hiraiso observatory started in December 1949 and continued until March 31, 2001.

The data used for producing radio alert were as follows:

(1) Sunspots, the geomagnetic field, the ground current, 200MHz solar radio, and the HF radio electric field.

(2) Information from domestic institutes and observatories, e.g., National Astronomy Observatory Japan, Research Institute of Atmospherics, Nagoya University, Kakioka Geomagnetic Observatory of Japan Meteorology Agency.

(3) International observation data shared with URSIGRAM.

URSIGRAM is a name of code for exchanging radio, optical and satellite data information (Nagaoka, 1933). The use of URSIGRAM was determined by the International Union of Radio Science (URSI) and started in 1928 in France. Information sharing with URSIGRAM was temporarily stopped in 1941 owing to WWII, and the redistribution was determined at the 9th URSI GASS. Japan started to send information on the ionosphere (RRL), solar activity, the solar corona, solar radio (National Astronomical Observatory, Japan), the geomagnetic field (Geomagnetic Observatory), and cosmic rays (RIKEN). These data were rapidly coded with URSIGRAM and sent with an HF broadcast JDD. URSIGRAM is still used but the JDD broadcast stopped in 1995.

The International Geophysical Year (IGY) is an international project proposed by ICSU for observing 12 different phenomena in geophysics including solar activity, the geomagnetic field, and the ionosphere (e.g., Nicolet, 1984). In IGY, an international organization named Space World Inverval (SWI) was established for predicting significant events, and RRL was assigned as an alert center in the west Pacific region. For this project, a special teletype line was constructed to connect RRL located in Kokubunji and the US base in Fuchu, western Tokyo. SWI was merged with the URSIGRAM user organization after IGY, and International URSIGRAM and World Days Service (IUWDS) was established under the umbrella of URSI, IUGG, and IAU.

There was a remarkable point for research and operation in space weather in this period. The special Committee on the Ionosphere was established in the Science Council of Japan in 1946. Not only the ionospheric scientists but also the scientists of related fields e.g., solar physics, cosmic ray, geomagnetism and geoelectricity joined the committee. The committee succeeded to receive budget from Japanese national government and contributed on building the future space weather community.

In those days, Hiraiso observatory developed a method for predicting geomagnetic storms using the location of solar flares and 200MHz solar radio burst data (Orchiston and Ishiguro, 2019). They succeeded in predicting two large magnetic storms on September 13, 1957 and February 11, 1958 with this method(Nishida, 2009, 2010). In addition, Hiraiso achieved the following significant results:

(1) They discovered the phenomenon of polar cap absorption, which is a region of strong HF absorption in the polar region that appears before geomagnetic storms. They revealed that this phenomenon is due to the precipitation of high-energy particles generated by a solar flare in the polar region (Obayashi, 1961).

(2) They carried out a statistical study on the global variation of ionospheric storms occurring after geomagnetic storms.(e.g., Obayashi, 1958; Ondoh and Obu ,1965)

(3) Hiraiso was selected as one of the standard sites for electric field measurement of WWV and WWVH (15MHz) to send precise data to CCIR (Comite consultative International pour la radio; International Telecommunication Union (ITU) in present) operationally from 1961 to 1995. Figure 4 shows an observation record of the receiving system (upper panel) and the record obtained by the previous system as a reference (lower panel) (e.g., Takenoshita, 1970, Ondoh and Obu, 1980).

(4) They studied the non-periodic structure in the ionosphere that generates the sporadic E region by receiving LORAN (Long-Range Navigation) A (1.85MHz). They discovered the horizontal movement of the non-periodic structure in the electron density by observation in 1963 (Sinno, et al., 1964).

The operational measurement of solar radio at a frequency of 200MHz began in 1952, using a 4×6-element equatorial ritual automatic tracking antenna. This system was initially used for supporting the optical measurement of the solar disk during cloudy weather, and become a more important system for radio alerts after the successful prediction of geomagnetic storms. Observation at a frequency of 9.5GHz with a 1.1m parabolic antenna began in 1960, and a 5m antenna with an operation frequency of 500MHz was added in 1961. More precise measurement of 200MHz solar radio waves with a 10m antenna began in 1967, and 100MHz measurement started in 1970. Figure 5 shows antennas used for measuring solar radio waves (Nishida, 2010).

In the 1970s, the paradigm of radio alert utility changed drastically: the importance of HF decreased with the increased use of ocean cables and satellite communications, and many of the important observations for radio alerts were carried out by satellites. Following this change, the framework of radio alert operation was restructured. One of the significant results in this period was the global observation of foF2 with the ISS-b satellite launched in February 1978. This led to the first ever publication of an foF2 global map.

ETS-II, Japan's first geostationary satellite, was launched in February 1977 to perform experiments on millimeter wave propagation (Fugono et al., 1980). In this mission, the scintillation of a beacon wave with a frequency of 136MHz and Faraday rotation was carried out for more than five years. The results showed that ionospheric scintillation was more significant than expected, and the relation between the ionospheric spread F and the region with a significant gradient of total electron content was clarified. Figure 6 shows the system for observing VHF scintillation and Faraday rotation of the beacon signal from ETS-II (Ishida et al., 1980).

Himawari, Japan's first meteorological satellite, had a high-energy proton detector on board as a satellite environment monitor, and the data were sent to Hiraiso via fax around 1978. This communication was motivated by an incident in which a geomagnetic storm affected the operation of Himawari: an ionospheric disturbance caused significant scintillation of a beacon signal and a ground-based antenna could not track the satellite. Because of this, the need for solar-terrestrial environment forecast increased, which includes the forecast and report of large geomagnetic storms and solar flares. This information has been distributed worldwide through the IUWDS network. Since operation of Himawari-4, Hiraiso observatory received SEM data directly in realtime and used for the operation.

Since 1978, a solar activity chart has been used for operational radio alerts. This chart is useful for sharing information over a wide area, which includes sun, solar wind, magnetosphere, and ionosphere information obtained from URSIGRAM. This chart is still used and is automatically plotted via machine processing.

In 1979, an international workshop for discussing solar-terrestrial environment forecast was hosted by NOAA/SEL. Many forecast users, forecast operators, and solar-terrestrial researchers attended and discussed the present status of forecasting techniques, new applications of forecasts, and future needs of forecasts at the workshop. Many critical issues to be resolved were pointed out, such as the gap between fundamental scientific results and forecast techniques, and the difficulty of obtaining real-time observation data. This meeting inspired Japanese researchers and forecasters, and RRL published the report of a committee on ionospheric observation, forecasting, and alerts in March 1985. This document suggested the simplification and rationalization of forecast operations and the development of a new forecast following the change in the radio utility and development of space utility. As one of the results of this report, RRL started a telephone service to provide radio alert information in April 1986.

A Japanese domestic project, “Research and Development of Space Weather Forecast System,” was launched in 1988. This project aimed to develop the activities of the radio alert operation and the west Pacific regional alert center in IUWDS. It was a 15-year plan, in which Hiraiso observatory was the main player in the first five years, to increase the power of the solar flare observation system and the computer network, in addition to carrying out fundamental research on the space environment to develop forecast algorithms. Examples of the achievements of the project are as follows:

(1) The construction of a solar radio spectrum observation system of 70–500MHz with a 10m parabolic antenna was completed in August 1988.

(2) Solar optical measurement with an H_alpha telescope of 5m diameter started in 1986.

(3) A plasma dynamic telescope was set up in 1987 and experimental measurement began in 1992. This system measured the solar atmospheric dynamics in H_alpha using the Doppler effect.

(4) The Space Environment Real-time Data Intercommunication Network (SERDIN) computer network was constructed in 1987, which was connected to SPAN (Space Physics Analysis Network) of NASA with a micro-VAX3500 computer. In 1991, SERDIN was connected to TISN (Tokyo University Science Network) through the NASDA center (Ishibashi, 2002).

The fundamental framework for disseminating space weather forecast services was prepared in the second five years of the project. A high-performance H_alpha solar telescope with a 4 million pixel digital imaging system was installed in Hiraiso and began operational measurement in 1994. In 1992, the solar radio telescope was also replaced with 6m parabolic and log-periodic antennas for receiving frequencies of 500–2500MHz and 25–70MHz, respectively. These antennas enabled the system to measure frequencies of 25–2500MHz continuously as a dynamic spectrometer. The Hiraiso Radio Spectrograph (HiRAS) system began operational measurement in 1993 and the data have been used for research on solar physics.

The NASA Advanced Composition Explorer (ACE) satellite enabled us to directly measure solar wind 1.5 million km upstream from the Earth, which is essential information for precise space weather forecasts. ACE was launched in 1997 and stationed at a Lagrange 1 point. CRL (Communications Research Laboratory; the successor of RRL) set up an 11m parabolic antenna in Koganei to receive the ACE signal for 24 hour tracking as part of a cooperative project with NOAA. The next-generation L1 satellite DSCOVR was launched on February 11, 2015 and Koganei has been receiving signals from DISCOVR since then (https://www.nesdis.noaa.gov/content/dscovr-deep-space-climate-observatory).

SEALION (Southeast Asia Low-latitude Ionospheric Network) is another example of an international cooperative project. The purpose of SEALION is to reveal the mechanism of ionospheric disturbances, which are especially significant in the equatorial region, e.g., equatorial plasma bubbles (EPBs). To measure the ionosphere along the same longitude and carry out conjugate measurements at the same magnetic latitude, multiple ionosondes have been installed in Thailand, Vietnam, Indonesia, and the Philippines in cooperation with universities and institutes in each country. The project started in 2003 and is still ongoing. Figure 7 shows the locations of the observation instruments in the SEALION project (e.g., Maruyama et al., 2014).

There are several activities involving space weather research and operations in Southeast Asian countries; however, they are smaller than those in America and Europe. Through the activity of SEALION, we realized the necessity of an international framework for discussing not only observations but also scientific research and operations related to space weather. AOSWA (Asia-Oceania Space Weather Alliance) was launched in 2010 and the first meeting was held in Bandung, Indonesia and involved five countries: Australia, India, Indonesia, Japan, and Malaysia. Currently, 17 countries are members of AOSWA, which has a biannual face-to-face workshop. The last one was held in Bandung on September 19–21, 2018 (https://aoswa.nict.go.jp/).

3 Present Trends in Space Weather Research and Operation in the world

3.1 National activities

Space weather seldom has an impact on society, but when it does, the effects could be significant. The most severe space weather event on record is the Carrington Event on September 1–2, 1859. At that time, some wired telegraph stations were damaged by geomagnetically induced current (GIC). If a similar event occurred today, what would be its social impact? The insurance company Swiss Re estimated the economic loss in each region in the world (Swiss Re, 2014). The table shows that the economic loss in high-latitude countries would be equivalent to that of the East Japan earthquake in 2011. United States has some of the most advanced measures to prepare for the social impact of extreme space weather disasters. They assigned space weather as one of the natural hazards equivalent to an earthquake, flood, or human pandemic in the US Strategic National Risk Assessment in 2011. The Space Weather Operations, Research, and Mitigation (SWORM) Working Group was established in 2014 and has discussed the strategy and national plan. Their action plan was published by the White House in 2015 (U.S. National Science and Technology Council, 2015a, 2015b) . As one of the results of the action plan, benchmarks for extreme space weather events have been discussed, and "Space Weather Phase 1 Benchmarks" was published by the White House in June 2018 (U.S. National Science & Technology Council, 2018). In addition, the international workshop "Space Weather as a Global Challenge" has been held since 2016 as a forum for discussing globally coordinated and consistent space weather services. Japan hosted the third workshop at the Japanese embassy in Washington D.C. in July 2018.

Steps to ensure national preparedness for space weather have also been taken in some other countries, such as the UK (U.K. Cabinet Office, 2015), and this global trend has been accelerating since 2016. In Japan, a report with the title, "The hazardous map for scientific suggestion against space weather disasters" was prepared in 2020 as part of the PSTEP (Project for Solar-Terrestrial Environment Prediction) project. PSTEP is a nationwide research collaboration supported by a Grant-in-Aid for Scientific Research on Innovative Areas from MEXT, Japan. There are two main goals of this project: to reveal some of the fundamental questions concerning the solar-terrestrial environmental system and to contribute to building a next-generation space weather forecast system to prepare for severe space weather disasters.

The X9.2 solar flare on September 6, 2017, was a major turning point for Japanese space weather operation. Many Japanese people paid attention to the event, which received extensive media coverage (60 TV news reports, 271 newspaper articles, 779 online reports on September 7 and 8). Since this phenomenon, the Japanese space weather operational framework has been strengthened. The domestic ionosphere and solar radio observation system been made more robust, and 24/7 space weather forecast operation started on December 1, 2019.

3.2 International activities

Space weather research and operation have also been discussed in many international organizations, including the UN. One of the most noteworthy organizations is the International Civil Aviation Organization (ICAO). Since the beginning of the 21st century, the use of the polar route has been increasing owing to increasing economic activity in east Asia, because the polar route is the shortest way between east Asia and Europe/the east coast of the US. On the other hand, the polar region is one of the most vulnerable regions to severe space weather. Large-scale solar flares can cause significant ionospheric disturbances in the polar region, including radio blackout, polar cap absorption, and ionospheric storms, which affect HF propagation and the precision of GNSS. In addition, radiation is a concern for frequent flyers, such as pilots and cabin attendants, because of the significant precipitation of solar energetic protons. ICAO has begun to prepare guidelines for avoiding such risks during severe space weather events as well as a framework to disseminate alerts/cautions based on space weather forecasts to civil aviation; Annex 3, which defines the meteorology information necessary for aviation, has been amended, and space weather centers have been selected to provide information to aviation users.

Through a series of audits, ICAO selected three groups as global space weather centers in November 2018: the UN, the PECASUS consortium (Austria, Belgium, Cyprus, Finland (leader), Germany, Italy, Netherlands, Poland, UK), and the ACFJ consortium (Australia, Canada, France and Japan), and their operation started on November 7, 2019.

International Space Environment Service (ISES) was established in 1996 as the successor of IUWDS. ISES is an international space weather service organization under ICSU comprising Regional Warning Centers (RWCs), Associate Warning Centers (AWCs), and Collaborative Expert Centers (CECs). At the beginning of 2020, there were 20 RWCs, one AWC, and one CEC in ISES. Each RWC is required to share data and forecasts and provide space weather products and services to users in the region, so the members of ISES are experts in space weather monitoring and forecast services. Many UN organizations who discuss space weather have received advice from expert members from ISES.

In addition to ICAO, several organizations under the umbrella of the UN, such as WMO, UN/COPUOS, and ITU, have been discussing international cooperation, preparedness for space weather disasters, and data sharing.

4 Role of Asian Countries

Through SEALION and AOSWA activities, several Asian countries have realized the importance of space weather monitoring; China, India, Japan, and South Korea are members of ISES, and Indonesia joined it in 2015. In addition, other countries, including Thailand and Malaysia, are interested in operational space weather services. Thailand is involved in ionospheric studies and has been working in partnership with SEALION. KMITL and Chiang Mai University are the main players of the project in Thailand. Recently, GISTDA, Thailand's national space agency, began to establish a framework for space weather research and operation as a part of space situational awareness.

Generally, it is difficult to perform ground-based observations in the equatorial region owing to a lack of infrastructure and the political situation. Southeast Asia has the advantages of political stability, a well-developed infrastructure.

With the increasing need for precise satellite positioning, it is necessary to know the influence of ionospheric disturbances on GNSS. Sub-meter positioning technology has led to the development of new technologies in construction, civil engineering, and agriculture. Southeast Asia is one of the most ideal regions for using positioning satellites because the number of usable satellites is higher than in other regions. However, ionospheric disturbances reduce the precision of positioning, In particular, EPBs have a very large gradient of electron density around their boundaries, which causes GNSS scintillation. Southeast Asia is a very advantageous area for researching the behavior of EPBs and developing a method of mitigating their influence on precise positioning.

5 Conclusions

Japan has a 100-year history in the research and development of radio propagation, which evolved into space weather monitoring and forecasting. It is necessary to monitor and forecast the space weather environment to enable the use of high-level information and communications technology. International cooperation in space weather research and operation is essential, and east and Southeast Asia have high potential to contribute to improving the space weather international framework, especially for the effective use of GNSS.

Acknowledgments, Samples, and Data

This study was partly supported by Grant-in-Aid 15H05813 (2015–2019), MEXT, Japan. The authors thank all of researchers, forecasters, and staff of Hiraiso observatory. The data collection of ionosondes, solar radio/optical measurement, and historical solar-terrestrial activity charts in Hiraiso was shown in http://wdc.nict.go.jp/IONO/wdc/index.html.

References

Fugono, N., R. Hayashi, and Y. Ishizawa (1980), ETS-II Experiments Part I: Japan’s First Geostationary Satellite, IEEE Transactions on Aerospace and Electronic Systems, AES-16, 5.

Ishibashi, H. (2002), Space Environment Information Service System, J. Comm. Res. Lab., 49, 4, Retrieved from http://www.nict.go.jp/publication/shuppan/kihou-journal/journal-vol49no4/0502.pdf

Ishida, T., N. Fugono, J. Tabata, M. Ohara, and T. Ishizawa (1980), Propagation experiment with Japanese satellite, ETS-II (KIKU-2), Acta Astronautica 7,3, 357-370, https://doi.org/10.1016/0094-5765(80)90089-2

Maruyama, T., J. Uemoto, M. Ishii, T. Tsugawa, P. Supnithi, T. Komolmis, (2014), Low-latitude ionospheric height variation as observed by meridional ionosonde chain: Formation of ionospheric ceiling over the magnetic equator, J. Geophys. Res., Space Physics, 119, 12, 10,595-10,607, https://doi.org/10.1002/2014JA020215

Nagaoka, H. (1933), Japanese ursigram, September to December, 1932, Terrestrial Magnetism and Atmospheric electricity, 38, 1, 65-66, https://doi.org/10.1029/TE038i001p00065

Nicolet, Marcel (1984), The international Geophysical Year (1957-1958): Great Achievements and Minor Obstacles (pp.303-320), 8, 4, IUGG Union Lectures, Springer.

Nishida, A. (2009), Early Japanese contributions to space weather research, 1945-1960, in Climate and Weather of the Sun-Earth system (CAWSES): Selected Papers From the 2007 Kyoto Symposium, edited by T. Tsuda et al., pp.1-22, TERRAPUB, Tokyo.

Nishida, A. (2010), The rise of space weather research in Japan, Space Weather, 8, S04001, doi:10.1029/2009SW000528.

Obayashi, T., (1958), Polar ionospheric disturbances associated with a severe magnetic storms, J. Geomag. Geoelectr., 10,1,28-35.

Obayashi, T. (1961), The solar geophysical events of November 1960, J. Geomag. Geoelectr., 13, 1-2, 33-41.

Okamura, S (Eds.), (1994), Growth of Wireless Telegraph (pp.51-52) in History of electron Tubes, Tokyo, : Ohmsha, Ltd,

Ondoh, T., and K. Obu (1965), Studies on Pre-sc polar ionosphere and HF radio Propagation over polar paths II. Pre-sc increase of WWV 20 and 25 Mc/s field intensity and of foF2 in high latitudes, J. Geomag. Geoelectr., 17, 1.45-57.

Ondoh, T., and K. Obu (1980), Prediction of HF communication disturbances by Pre-SC HF field increases on polar crossing the auroral zone, Solar Terrestrial Predictions Proceedings, 4, 55, 21-30.

Orchiston, W., and M. Ishiguro, (2019), Highlighting the history of Japanese radio astronomy. 6: Early solar monitoring at the Radio Research Laboratories of the Ministry of Posts and Telecommunications, Hiraiso, J. Astronomical History and Heritage, 22(2), 328-338.

Oughton, E., A. Skelton, R. B. Horne, A. W. P. Thomson, and C. T. Gaunt (2017), Quantifying the daily economic impact of extreme space weather due to failure in electricity transmission infrastructure, Space Weather, 15(1), 65-83, doi.org/10.1002/2016SW001491

Oughton, E. J., M. Hapgood, G. S. Richardson, C. D. Beggan, A. W. P. Thomson, M. Gibbs, C. Burnett, C. T. Gaunt, M. Trichas, R. Dada, R. B. Horne (2019), A Risk Assessment Framework for the Socioeconomic Impacts of Electricity Transmission Infrastructure Failure Due to Space Weather: An Application to the United Kingdom, Risk Analysis, 39(5), 1022-1043, doi.org/10.1111/risa.13229.Rishbeth, H., (1994), What became of Appleton's ionosphere?, J. Atmos. Terr. Phys., 56, 6, 713-725, https://doi.org/10.1016/0021-9169(94)90128-7

Shiomi, T., and M. Hatori (eds) (2000) Digital Broadcasting, Wave Summit Course, Ohmsha. Ltd, Tokyo.

Sinno, K., C. Ouchi and C. Nemoto, (1964), Structure and Movement of Es Detected by Loran Observations, J. Geomag. Geoelectr., 16, 2, 75-88, Retrieved from https://www.jstage.jst.go.jp/article/jgg1949/16/2/16_2_75/_pdf

Swiss Re (2014), Space Weather Impacts a Risk to Society? Economic Aspects from an Insurance/Reinsurance Point of View, Retrieved from https://www.swpc.noaa.gov/sites/default/files/images/u33/NOAA-MASTER.pdf

Takenoshita, Y.(1970), On HF Propagation Dsiturbances from March 6-10, 1970, Data on solar-geophiysical activity associated with the major geomagnetic storm of March 8, 1970, report UAG-12 Part 1, compiled by Lincoln, J. V., and D. B. buchnam, p227.

U. K. Cabinet Office, Space Weather Preparedness Strategy, Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/449593/BIS-15-457-space-weather-preparedness-strategy.pdf

U. S. National Science & Technology Council (2015a), National Space Weather Action Plan, Retrieved from https://www.sworm.gov/publications/2015/swap_final__20151028.pdf

U. S. National Science & Technology Council (2015b), National Space Weather Strategyt, Retrieved from https://www.sworm.gov/publications/2015/nsws_final_20151028.pdf

U. S. National Science & Technology Council (2018), Space Weather Phase 1 benchmarks, Retrieved from https://www.whitehouse.gov/wp-content/uploads/2018/06/Space-Weather-Phase-1-Benchmarks-Report.pdf

Figure 1. Photo of the receiving experiment of HF radio waves from US KGO station. Center: Noboru Marumo, the second director of the Hiraiso branch, Left: Eijiro Takagishi, the third director of the Hiraiso branch. This was the first time that radio waves passing over the Pacific Ocean were received.

Figure 2. Photos of the HF radio communication system developed at Hiraiso around 1925. (a) Transmitter system under development. The oscillator circuit is located near the center. (b) Talking room, which used a double-bottom microphone made by Western Electric Company.

Figure 3 Photos of the ionosonde system around 1934–1935. (a) Transmitter installed in the Hiraiso branch. (b) Receiver installed in the Isohama branch.

Figure 4 (upper panel) Example of observation record of the receiving system as a standard site of electric field measurement of WWV and WWVH (15MHz), and (lower panel) the same record obtained with the previous system as a reference.

Figure 5 Photos of antennas for measuring solar radio waves. (a) 4×6-element electric ritual automatic tracking antenna installed in 1952. (b) 5m phi parabolic antenna (c) 1.1m phi parabolic antenna. (d) 10m phi parabolic antenna.

Figure 6 System for observing VHF scintillation and Faraday rotation of beacon signal from ETS-II.

Figure 7 Map of locations of instruments that measure equatorial ionospheric disturbances, e.g., EQBs, in SEALION project.

Figure 1.

Figure 2(a).


JHBB
HIRAISO, JAPANUJO

Figure 2(b).

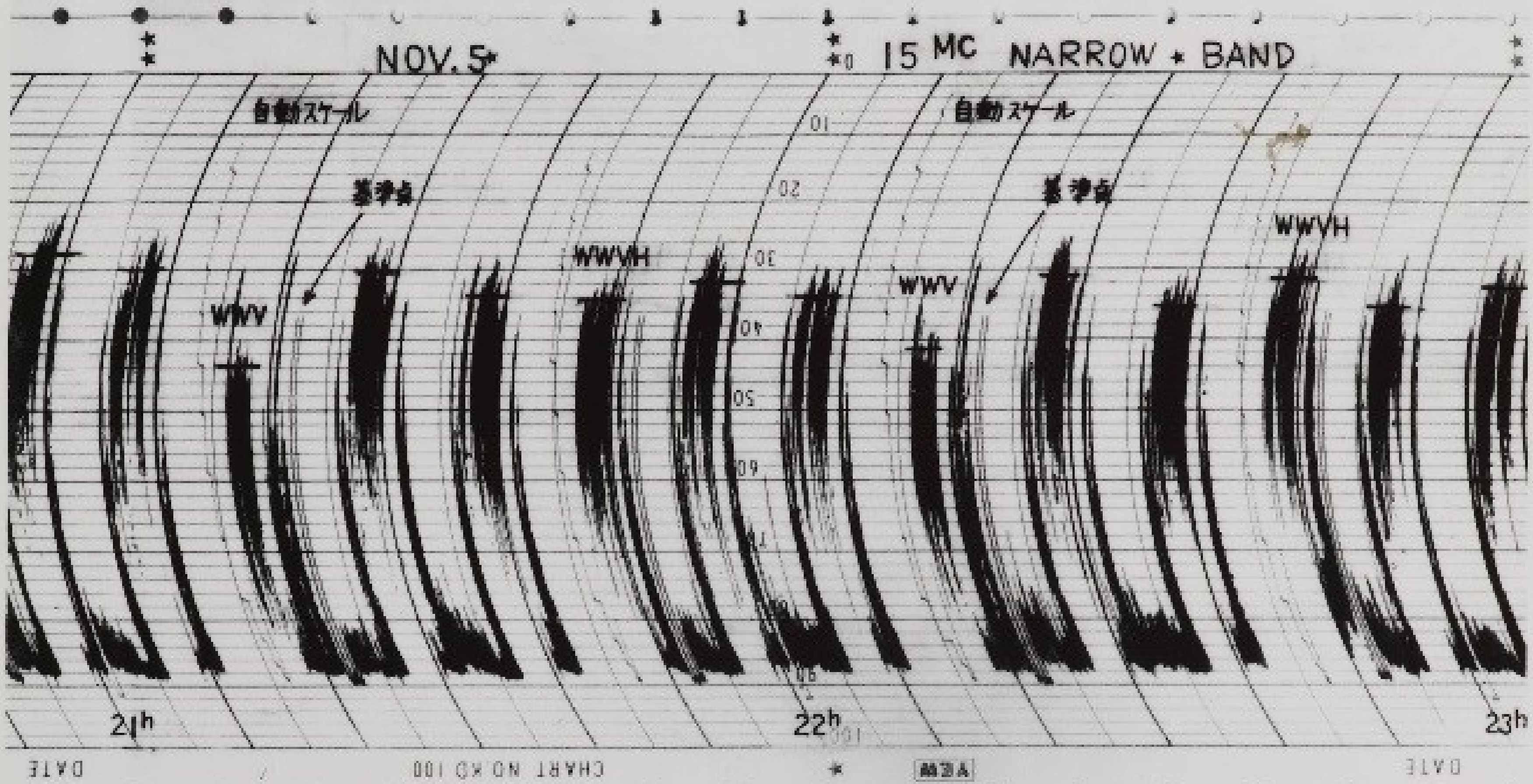

JHBB
HIRAISO
JAPANUJO
EAD-20

Figure 3(a).


危
險

Figure 3(b).

Figure 4.


NOV. 5
15 MC NARROW BAND
自動スケール
基準点
WWV
WWVH
21h
22h
23h

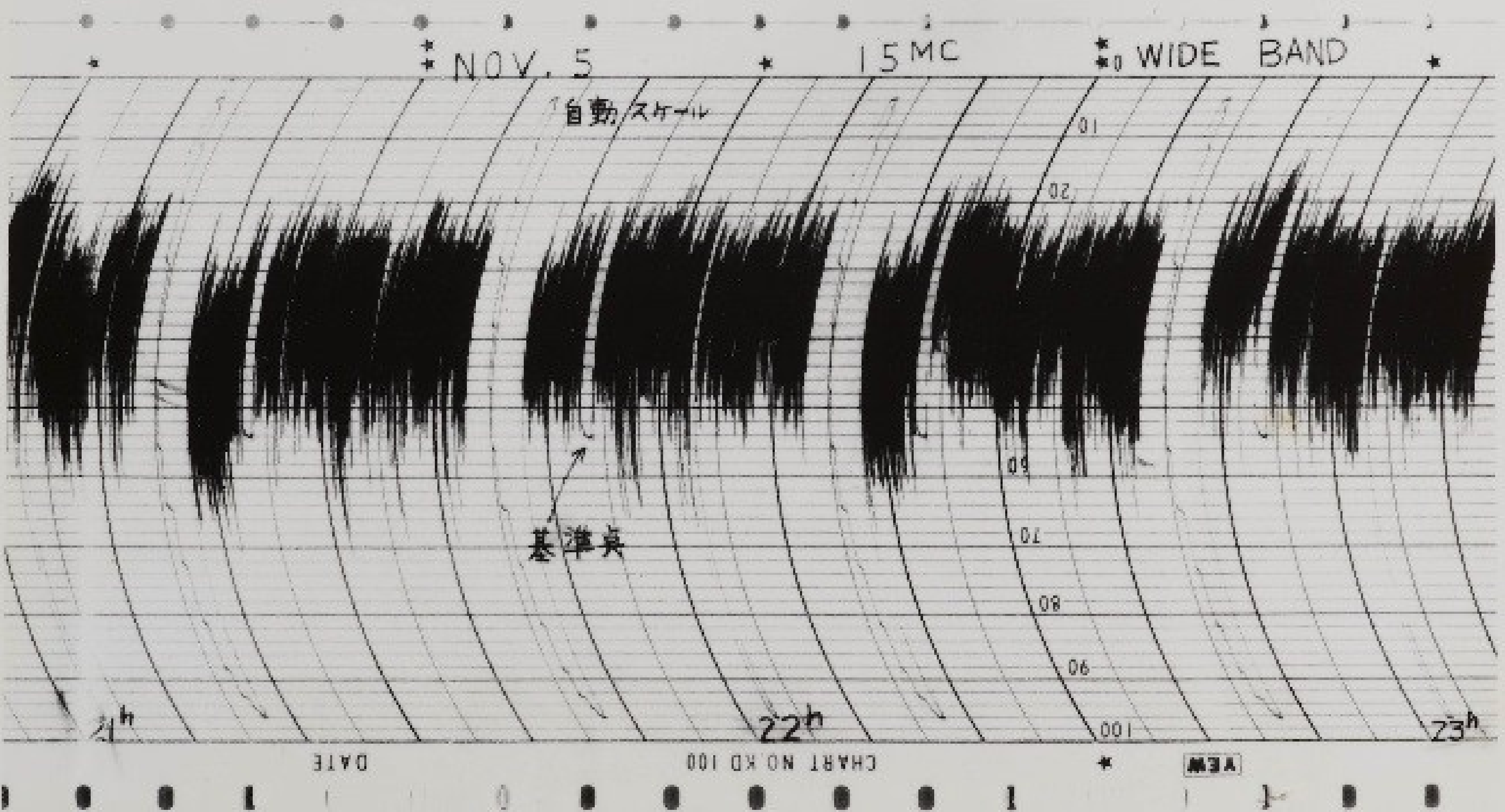

NOV. 5
15 MC WIDE BAND
自動スケール
基準点
21h
22h
23h

Figure 5(a).

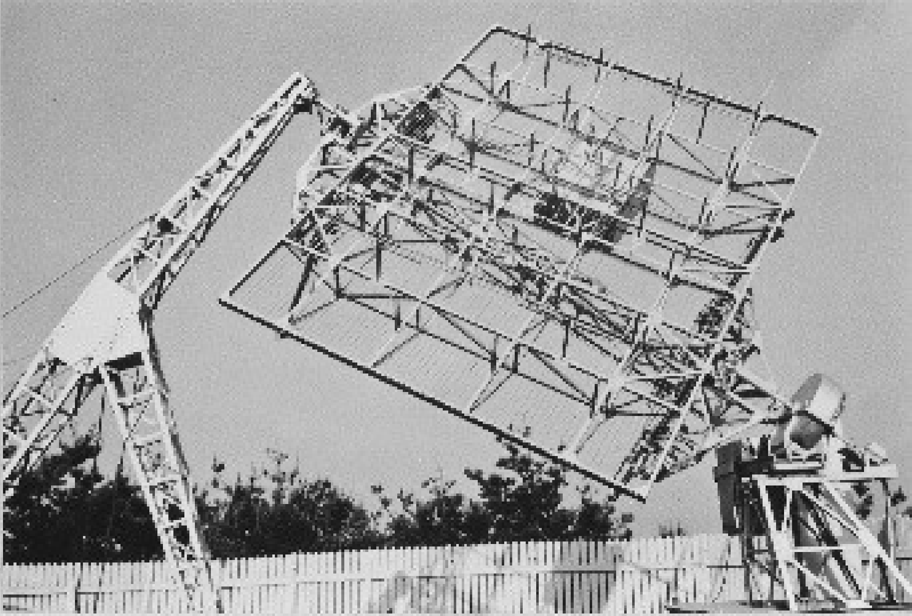


Figure 5(b).

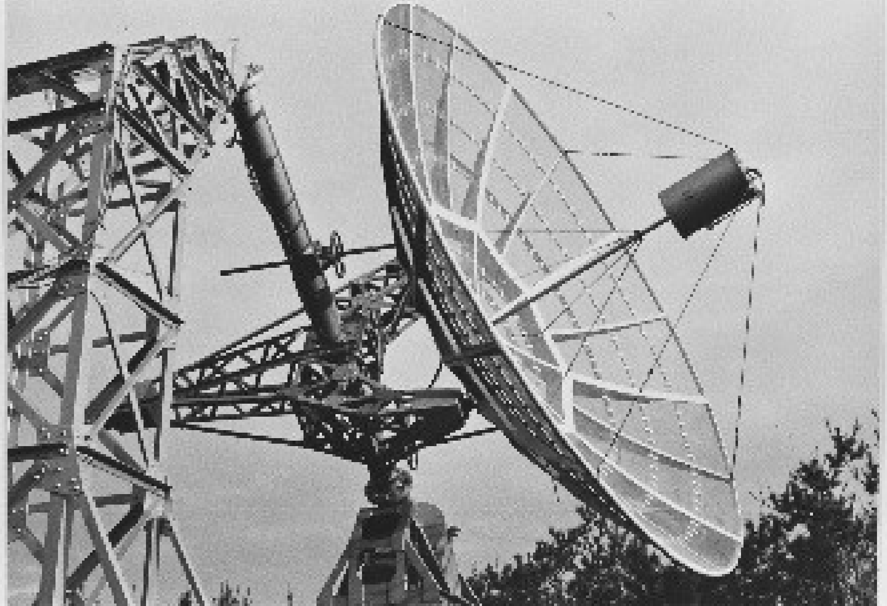
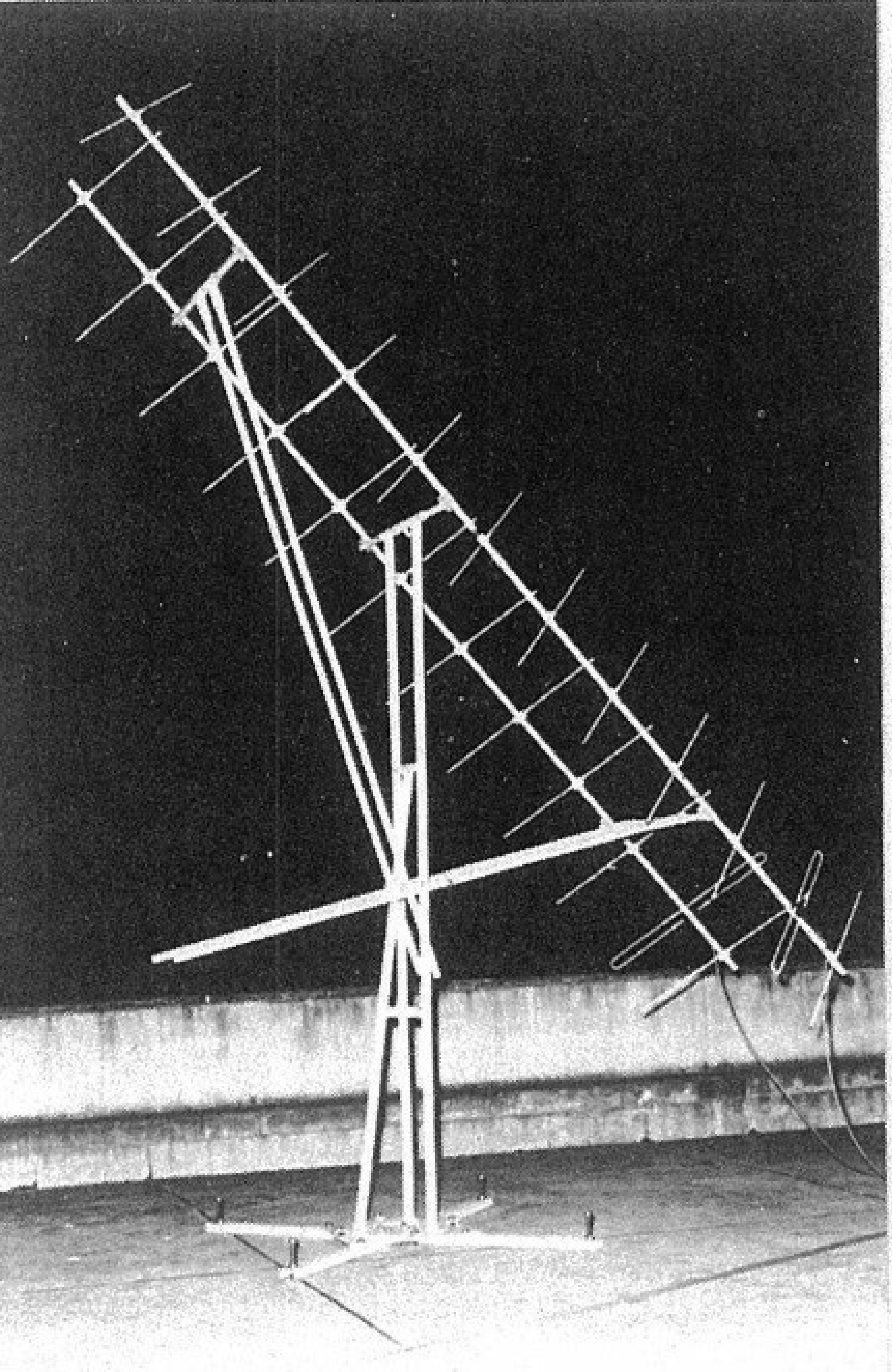


Figure 5(c).

Figure 5(d).

Figure 6.



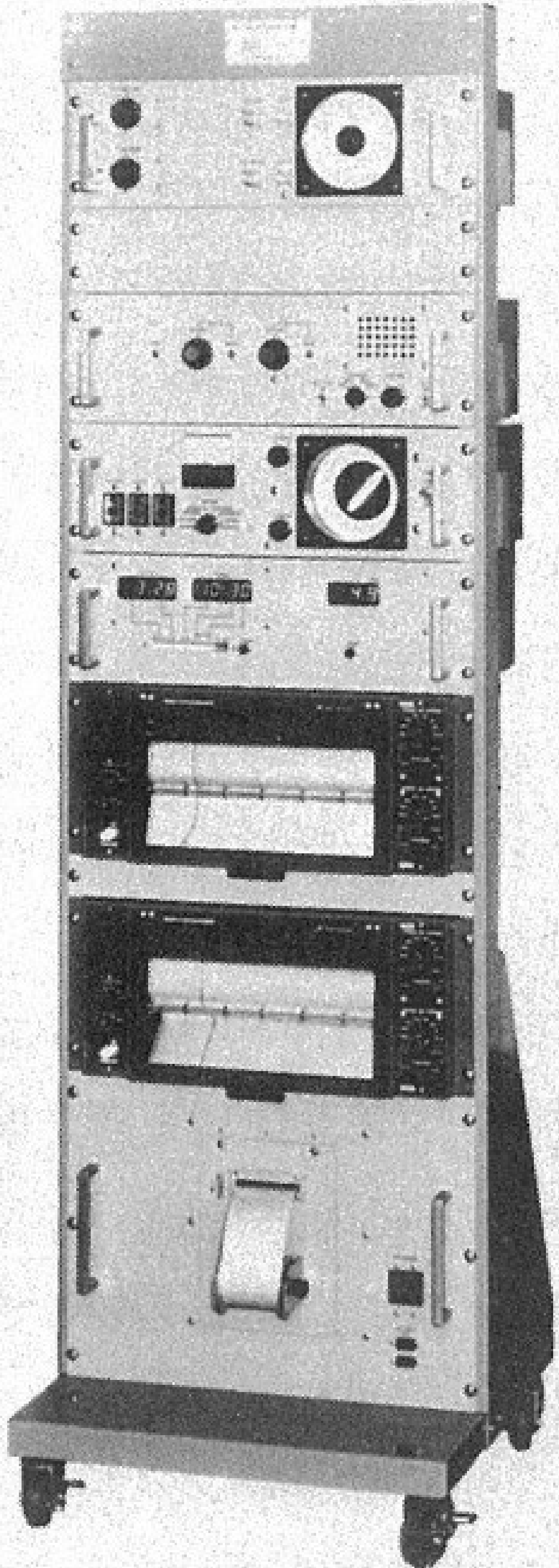


Figure 7.

チェンマイ Chiang Mai
バンコク Bangkok
チュンポン Chumphon
セブ Cebu
磁気赤道
Magnetic Equator
プーケット
Phuket
バクリウ
Bac Lieu
赤道
Equator
コトタバン Kototabang
イオノゾンデ
Ionosonde
GPSシンチレーション
GPS Scintillation
GPS全電子数
GPS TEC
磁力計
Magnetometer
全天大気光カメラ
All-Sky Imager
HF方向探査施設
HF TEP