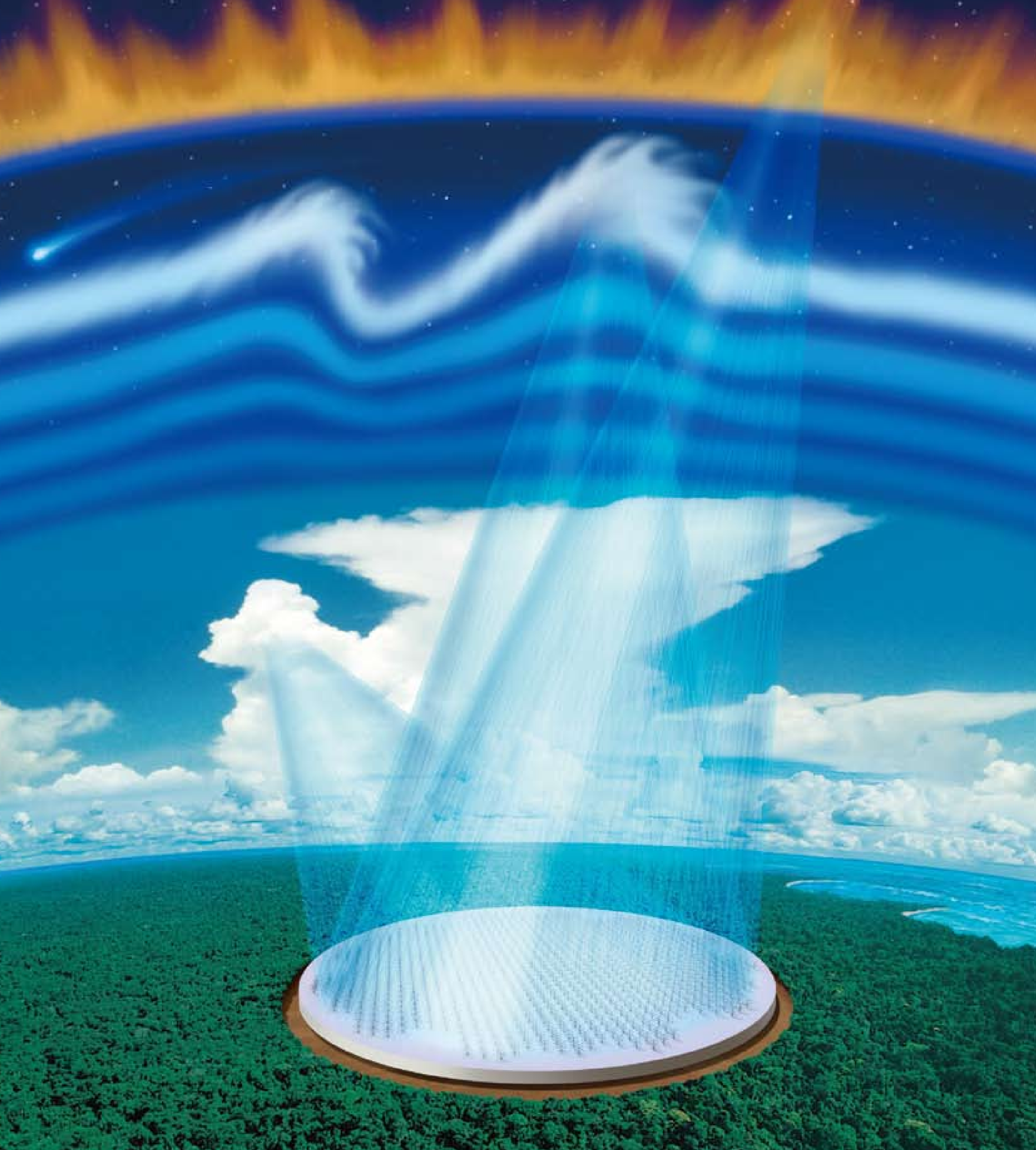
Japan-Indonesia collaborative study of equatorial atmosphere

～15 years of the Equatorial Atmosphere Radar and beyond～



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～15 years of the Equatorial Atmosphere Radar and beyond～

Research Institute for Sustainable Humanosphere (RISH)
Kyoto University, Japan

National Institute of Aeronautics and Space (LAPAN)
Indonesia

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1. Introduction

The western Pacific region called the Indonesian Archipelago is the center of the intense atmospheric motions and global atmospheric changes. However, the mechanisms of the atmospheric changes and fluctuations were not clear due to the sparseness of observation data in that region. Research Institute for Sustainable Humanosphere (RISH), Kyoto University, Japan and National Institute of Aeronautics and Space (LAPAN), Indonesia started scientific collaboration in the middle 1980 to overcome this problem. Table 1 shows list of historical events during 30 years of this collaboration. The first contact from RISH (the institute name at the time was "Radio Atmospheric Science Center (RASC)") was a plan of "Equatorial Radar" that was the gigantic radar planned right over the geographic equator. We pursued the plan with intensive site survey for the facility. Meanwhile in 1990, we conducted the first observation campaign of the equatorial atmosphere by using radiosondes. Then we started installation of two compact radars in 1992 at PUSPIPTEK, and a Middle-Frequency (MF) radar in 1995 at Pontianak. During the course of these research efforts, we reached the construction of the Equatorial Atmosphere Radar (EAR). Collaborative study between RISH and LAPAN was very much enhanced by the EAR together with timely research project "Coupling Processes in the Equatorial Atmosphere" (2001-2007 lead by Prof. S. Fukao). The EAR was successfully operated under this collaboration. We conducted the 10th anniversary of the EAR in 2011 at the RISTEK Auditorium in Jakarta. This document summarizes this long-time scientific collaboration between Japan and Indonesia. We also discuss future direction centered around the new facility Equatorial Middle and Upper atmosphere (EMU) radar.

Table1: History of scientific collaboration between RISH and LAPAN

1986	First visit to LAPAN observatories in Pontianak (west Kalimantan) and Biak (Irian Jaya)
1987	Intensive site survey for "Equatorial Radar" project (Pontianak and west Sumatra)
1990	Campaign observations with balloon-borne radiosondes at the LAPAN observatory in Watukosek, east Jawa
1992	Establishment of a radar observatory in PUSPIPTEK, Serpong, west Jawa (Meteor Wind Radar and Boundary Layer Radar)
1992-	Radiosonde campaigns in LAPAN observatories (Bandung, PUSPIPTEK, Pontianak, etc.)
1995	Establishment of an MF radar observatory in Pontianak
2001	Establishment of the Equatorial Atmosphere Radar (EAR) in Kototabang, West Sumatra
FY2001-2006	Grant-in-Aid for Scientific Research on Priority Areas "Coupling Processes in the Equatorial Atmosphere (CPEA)" lead by Prof. S. Fukao
FY2008-2010	JSPS Asia-Africa Science Platform Program "Elucidation of ground-based atmosphere observation network in equatorial Asia" lead by Prof. T. Tsuda
FY2010-2012	Strategic Fund for Promotion of Science and Technology "Research enhancement and system development for space weather in Indonesia" lead by Prof. M. Yamamoto
2011	10th anniversary of the EAR at RISTEK, Jakarta
2013	Research project "Study of coupling processes in the solar-terrestrial system" (leader: Prof. T. Tsuda) was proposed to Japan Science Council, and was approved as a large research project in Master Plan 2014.
2014	The project included as one of 11 new projects in Roadmap 2014 of Japanese Minister of Education, Culture, Sports, Science, and Technology (MEXT).
2014	RISH and LAPAN signed Letter of Intent for the new project of the Equatorial MU (EMU) radar that is included in the large research project.
2016	15th anniversary of the EAR at Jakarta

2. Equatorial Atmosphere Radar (EAR)

The mechanisms which cause atmospheric variability in the western Pacific region are considered to have hierarchical and multiple structures, which require us to observe the atmosphere with various scales. As a key facility for these studies, we built the EAR at the Equatorial Atmosphere Observatory, Kototabang, West Sumatra, Indonesia (0.20°S, 100.32°E) in 2001 [Fukao et al., 2003]. Figure 1 shows the antenna field of the EAR and its location. The operation of the EAR is based upon the memorandum of understanding (MOU) between RISH and LAPAN.

The EAR is an atmospheric radar operated at 47-MHz center frequency. Table 2 lists the specifications of the EAR. A peak output power is 100 kW. The EAR has a circular active phased antenna which consists of 560 three-element Yagi antennas. As shown in Figure 1, each Yagi antenna is driven by a solid-state transmitter/receiver module with a peak output power of 180 W. Owing to the active phased array antenna, the EAR can electronically change beam directions with a rate up to 5,000 times per second. The EAR is designed to measure vertical and horizontal wind velocities and turbulence in the troposphere and the lower stratosphere (up to 20 km altitude) with high time and height resolutions (less than 1 minute and 150 m, respectively). The EAR is also able to observe ionospheric irregularities such as plasma bubbles above approximately 90 km altitude. The EAR started the continuous observations of the equatorial atmosphere in June 2001. As shown in Figure 2, it continues until today, providing us with valuable database for the Earth's environmental research. Since the establishment of the EAR, many instruments have been installed in the radar site through collaborations with other research institutes as shown in Figure 3, such as Rayleigh and sodium lidars, FM-CM ionosonde, VHF radar, meteor radar, X-band meteorological radar, all-sky imager, Fabry-Perot interferometer, micro-rain radar, ceilometer, disdrometer, optical rain gauge, radiometer, and GPS receivers.

The EAR can observe gravity wave behaviors, turbulence generation, and wind motions in the troposphere and the lower stratosphere. One of the major achievements from the EAR is finding of Kelvin-wave modulation of the tropopause region [Fujiwara et al., 2003], which provided direct evidence that mixing of stratospheric air and tropospheric air occurred by the Kelvin wave breaking. Also, high-resolution wind and turbulence measurements by the EAR greatly contributed to clarify the generation mechanisms of deep cumulus convection that further excites atmospheric gravity waves [e.g., Ratnam et al., 2006]. From the ionosphere observations, the pulse-to-pulse antenna beam-scan measurement by the EAR revealed the spatial evolution of equatorial plasma bubbles, which propagate and affect electromagnetic phenomena in the equatorial thermosphere [e.g., Fukao et al., 2004].

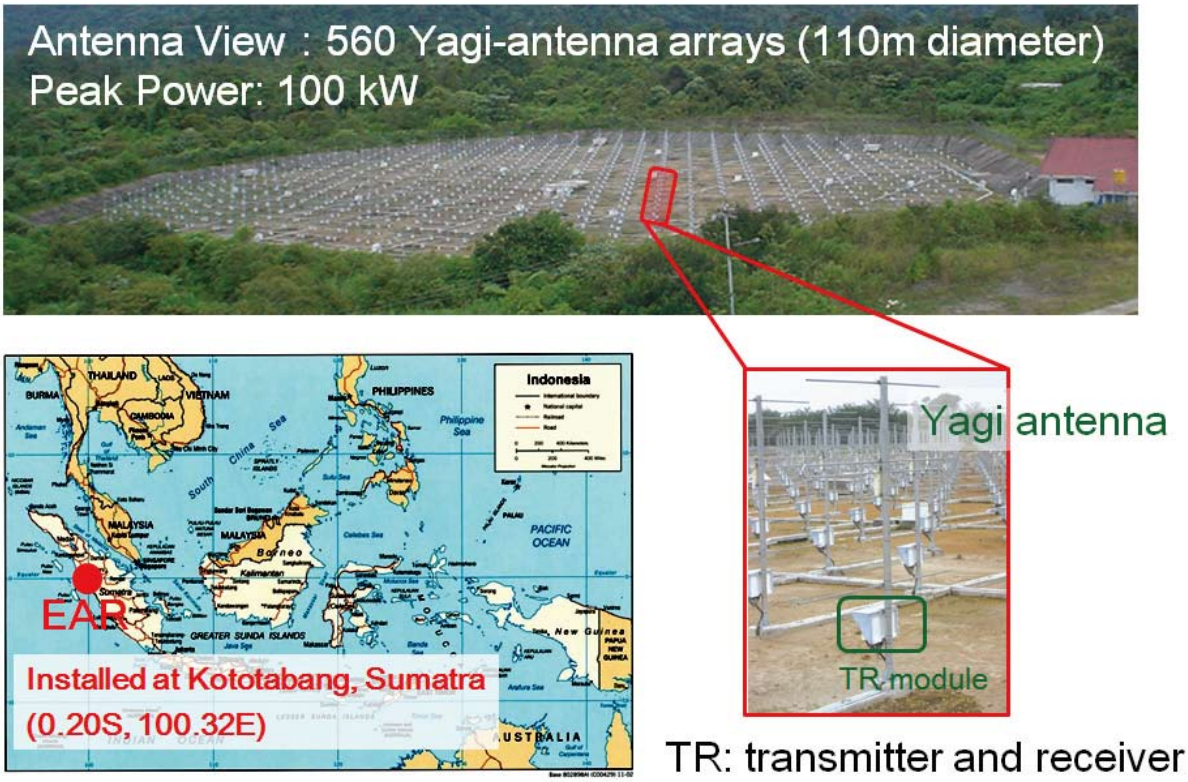

Figure 1: Overview of EAR (top) with configuration of each Yagi antenna (bottom right) and location of the EAR site (bottom left).

Table 2: Specifications of the EAR

Location	0.20°S, 100.32°E
Frequency	47.0 MHz
Output power	100kW (Peak envelope)
Antenna system	Quasi-circular active phased array (110 m diameter, 560 three element Yagis)
Beam width	3.4° (half-power, one-way)
Beam direction	Anywhere (within 30° zenith angle)

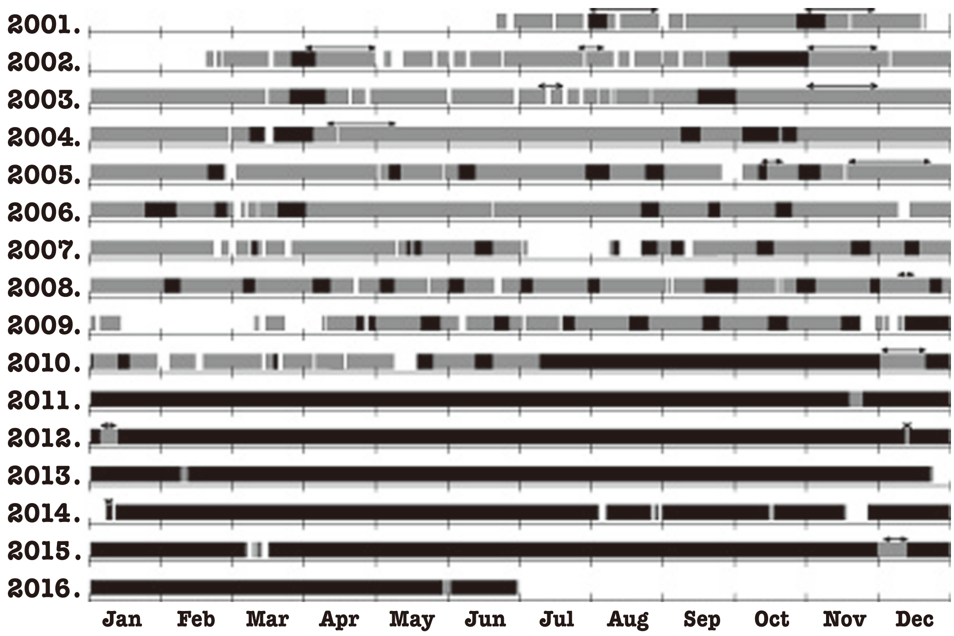

Figure 2: Operation period of the EAR since June 2001. Gray rectangles are the period of the troposphere and lower stratosphere measurements (hereafter ST measurement). Black rectangles are the periods that ionosphere and ST measurements were carried out simultaneously.

Figure 3: Equipment installed at the Equatorial Atmosphere Observatory. (❶ FM-CW ionosonde, ❷ VHF radar, ❸ Meteor radar, ❹ X-band meteorological radar, ❺RASS speakers, ❻ All-sky imager, ❼ Fabry-Perot interferometer, ❽ Micro-rain radar, ❾ Ceilometer, ❿ Disdrometer, ⓫ Optical rain gauge, ⓬ Radiometer, ⓭ GPS receiver, ⓮ Lidar)

3. Research Project "Study of Coupling Processes in the Solar-Terrestrial System"

The solar energy can mainly be divided into two categories; the solar radiation, and the solar wind. The former maximizes at the equator, generating various disturbances over a wide height range, causing vertical coupling processes of the atmosphere between the troposphere and middle and upper atmospheres by upward propagating atmospheric waves. The energy and material flows that occur in all height regions of the equatorial atmosphere are named as "Equatorial Fountain". These processes from the bottom also cause various space weather effects, such as satellite communication and GNSS positioning. While, the electro-magnetic energy and high-energy plasma particles in the solar wind converge into the polar region through geomagnetic fields. These energy/particle inflow results in auroral Joule heating and ion drag of the atmosphere particularly during geomagnetic storms and substorms.

The study of these coupling processes in the solar-terrestrial physics (STP) has been internationally organized by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) under the International Council for Science (ICSU). Since the International Geophysical Year (IGY) in 1957, many international research programs of about five year long have been continuously conducted. Recently, Climate and Weather of the Sun-Earth System (CAWSES) was conducted during 2004-2013 [Tsuda et al., 2015]. Now the new project Variability of the Sun and Its Terrestrial Impact (VarSITI) is running in 2014-2018 by SCOSTEP (http://www.varsiti.org/).

We propose the research project "Study of coupling processes in the solar-terrestrial system" in the period of 2016-2025 to clarify these overall coupling processes in the solar-terrestrial system from the bottom and from above through high resolution observations at key latitudes in the equator and in the polar region. In this project we will establish a large radar with active phased array antenna, called the Equatorial Middle and Upper atmosphere (EMU) radar, in west Sumatra, Indonesia. We will participate in construction of the EISCAT_3D radar in northern Scandinavia, too. These radars will enhance the existing international radar network. We also develop a global observation network of compact radio and optical remote-sensing equipment from the equator to polar region.

Our proposal is widely supported by national and international scientific communities. Table 3 lists scientific communities and institutions that are related to our proposal. The development of the EMU radar has gained full support from the Indonesian Government, similar to the EISCAT_3D project that progressed with international discussions with European countries and China. In Japan, this project is formally supported. It has been selected as one of 27 important projects in the Master Plan 2014 that was endorsed by the Science Council of Japan (http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t188-1.pdf). Among the 27 proposals, Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) further selected top 11 projects in the Roadmap 2014, in which our proposal has been included (http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu4/toushin/__icsFiles/afieldfile/2015/11/17/1351171_1_1.pdf).

Table 3: List of related scientific community and research organizations

Japan:

JpGU (Japan Geoscience Union) Section for Space and Planetary Sciences,
SGEPSS (Society of Geomagnetism, Earth, Planetary and Space Sciences),
Meteorological Society of Japan,
IEICE (The Institute of Electronics, Information and Communication Engineers).

International:

ICSU/SCOSTEP (Scientific Committee on Solar-Terrestrial Physics),
ICSU/URSI (International Radio Science Union),
ICSU/IUGG (International Union on Geodesy and Geophysics),
Science steering group (SSG) for the MST radar workshop,
ISWI (International Space Weather Initiative),
IEEE Milestone for the MU radar (May, 2015).

Indonesia:

RISTEKDIKTI (State Ministry of Research and Technology and Higher Education),
LAPAN (National Institute of Aeronautics and Space),
BMKG (Indonesian Agency for Meteorology, Climatology and Geophysics),
BPPT (Agency for the Assessment and Application of Technology),
ITB (Bandung Institute of Technology), etc.

EISCAT scientific association

Established in 1975 by FRG (Federal Republic of Germany), UK, France,
Norway, Sweden, and Finland.
Japan and China joined in 1996 and 2007, respectively.

4. Equatorial Fountain

Cumulonimbus convection is active in the equatorial atmosphere. It generates various types of atmospheric waves that propagate upward to transport energy and momentum into the upper atmosphere including the ionosphere [e.g., Tsuda, 2014]. Also, different kinds of materials (atmospheric minor constituents) originating at low- are mid-latitude regions are converging into the equatorial region and blown upward through the tropopause. They eventually reach the middle atmosphere and spread to the whole globe. In the upper atmosphere, there are plasma disturbances, and the equatorial ionization anomaly (EIA) is generated around the geomagnetic equator [e.g., Appleton, 1946; Balan and Bailey, 1995; Rishbeth, 2000; Lin et al., 2007]. The energy and material flows that occur in all height regions of the equatorial atmosphere are named as “Equatorial Fountain”. Figure 4 shows the conceptual diagram of the Equatorial Fountain. In our new research project “Study of Coupling Processes in the Solar-Terrestrial System”, we propose to develop EMU radar which is a new radar with transmitting power 10 times larger than the existing EAR. The high sensitivity of the EMU radar will enable the measurement of winds in the troposphere, middle atmosphere and thermosphere/ionosphere. Using the EMU radar we will discover and clarify unknown phenomena of the Equatorial Fountain in wide range of altitudes, focusing on the following three major scientific subjects:

Material fountain: Different kinds of materials in the atmosphere are emitted from land-and sea-surface in the equatorial region. They contribute to the generation of cumulus and/or cirrus clouds while circulating in the troposphere. The materials flow into the stratosphere through the tropopause like a fountain, and reach widely to the middle and high latitude regions.

Energy fountain: Atmospheric waves originating in the troposphere transfer their energy and momentum like a fountain up to the middle atmosphere, where peculiar long-term waves and irregularities are induced.

Plasma fountain: The ionospheric plasma around the geomagnetic equator is blown upward by the dynamo electric field induced by the background neutral winds, which is known as plasma fountain. A variety of energy exchange and plasma-density fluctuations are induced through the coupling between the dynamics and electromagnetics.

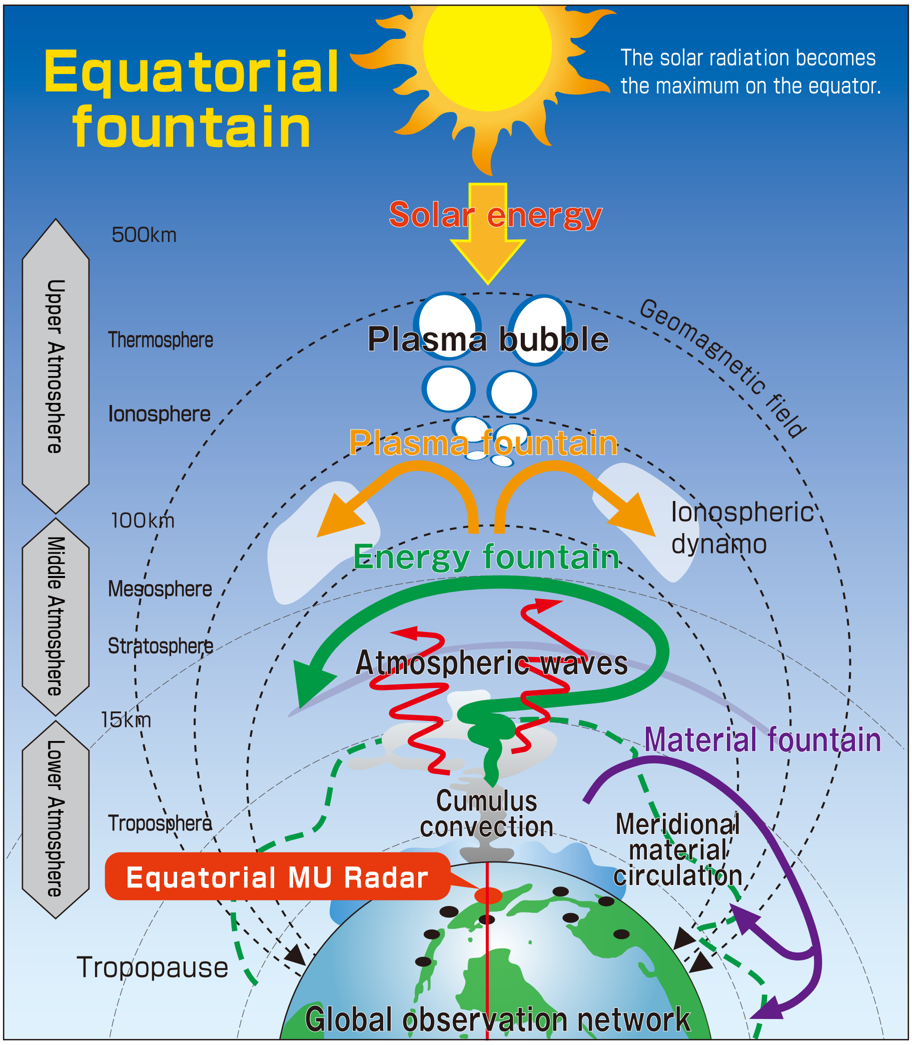

Figure 4: Phenomena in the equatorial atmosphere.

5. The Equatorial Middle and Upper Atmosphere (EMU) Radar

We developed the MU radar in Japan, which is the first application of active phased array antenna to atmospheric radars, and extended it to similar radar systems in oversea facilities. This technical innovation has been adopted by foreign research groups for the development of other radars. The MU radar was selected as IEEE Milestone which honors significant technical achievements in all areas associated with IEEE (The Institute of Electrical and Electronics Engineers). Based on this heritage, the state-of-the-art techniques established by the MU radar will be used for the EMU radar.

The EMU radar, a large-aperture Doppler radar operating at 47 MHz, will be installed at the north side of the EAR at Kototabang in West Sumatra, Indonesia. The specifications of the radar are given in Table 4. The antenna system and the system block diagram of the EMU radar is shown in Figure 5 and 6, respectively. The antenna is an active phased array consisting of 1045 three-element crossed Yagi antennas. Each of the 1045 antennas is equipped with a solid-state transmitter-receiver (TR) module with 500 W (peak envelope power; PEP) output, so the total output power is about 500 kW (PEP). The antenna beam can be steered electrically on a pulse-to-pulse basis by controlling phase shifters in the TR modules. The large antenna array of 160-m diameter and 500 kW (PEP) output enables the EMU radar to have 10-times higher sensitivity than the EAR and comparable sensitivity to that of the MU radar. The transmitted pulse length is variable but has a minimum length of 0.5 μs, corresponding to a height resolution of 75 m. In order to increase sensitivity, binary phase codes, such as Barker and complementary codes [e.g., Schmidt et al., 1979], are utilized for pulse compression techniques. Spano codes [Spano and Ghebrebrhan, 1996], which are an extension of complementary codes, are also applicable.

The Yagi antennas are located on grids of equilateral triangles with a side that is 4.5 m (approximately 0.7 wavelength) long as shown in Figure 5. For this element spacing, no grating lobe is formed at beam positions within 30 deg. around the zenith. For radar imaging measurements [Palmer et al., 1998], the 1045 Yagi elements can be divided into 55 sub-arrays, each of which is composed of 19 Yagi antennas and an identical number of TR modules. In-house equipment consists of a multi-channel signal processer system with a digital modulator/demodulator unit and a host computer which is a Linux-based personal computer. A maximum of five frequencies can be chosen between 46.5 MHz and 47.5 MHz in steps of 1 kHz for range imaging measurements [Luce et al., 2001]. The EMU radar will be operated under close collaboration with LAPAN following the success of the EAR experiment since 2001.

In the radar site there are many other measurement instruments as shown in Figure 3. Various observation techniques from these instruments are very useful to obtain various atmospheric parameters, complementing the results with EMU. The coordinated observations using the EMU radar and these collocated instruments are expected to clarify dynamics, photo-chemistry and electro-dynamics occurring in the equatorial atmosphere. In particular, Radio Acoustic Sounding System (RASS) [Tsuda et al., 1994] was adopted to EAR for obtaining atmospheric temperature in the troposphere up to about 10 km [Alexander et al., 2006]. By applying RASS to the EMU radar, having 10 times more sensitive compared to EAR, we will be able to raise the maximum altitude of temperature profiles as high as 23 km [Matuura et al., 1986; Sarma et al, 2008]. Then, we can continuously observe temperature variations in the upper troposphere and lower stratosphere (UTLS) region, including the tropical tropopause. For the study of the middle and upper atmosphere, we have been successful on EAR observations of ionospheric irregularities like plasma bubble. The EAR's pulse-to-pulse beam steering capability enabled us to reveal separately the time-spatial structures of plasma bubbles [e.g., Fukao et al, 2004; Fukao et al, 2006]. The new EMU radar system will add three more capabilities; 1) mesosphere experiment with turbulent echoes at the height region of 60-90 km, 2) incoherent scatter (IS) experiment, and 3) radar imaging experiment. 1) and 2) is possible from higher sensitivity and circular polarization of the EMU radar. 3) is based on the spatial interferometry with 55-channel receiver system. The IS experiment should be first over the Asian sector with the active phased-array radar, and we can obtain information of the background ionosphere. The radar imaging, on the other hand, will give us more detailed information of the ionospheric irregularities while larger structures are observed by the multi-beam experiment.

The use of the EMU radar will be open to the international community through international collaborative research programs. The EMU radar will also be utilized for education of young scientists from all over the world.

Table 4: Specifications of Equatorial MU (EMU) radar system

EMU System Parameter	Value
Antenna Specifications	
Antenna type	Crossed Yagi antennas
Configuration	Quasi-circular array of diameter 160 m
Aperture	About 16,000 m^2
Full antenna beam width	2.4 deg. (one-way half-power full width)
Function	Electronic beam steering pulse to pulse
Beam directions	Arbitrary direction within a zenith angle of 30 deg.
Polarization	Circular polarization
Transmit System	
Configuration	1045 solid-state TR modules
Maximum peak output power	500 kW
Maximum duty ratio	10%
Operating center frequency	47.0 MHz
Pulse resolution	75 m (min.)
Receive System	
Allocated bandwidth	6 MHz
Receiver channels	55+9 channels of synchronous quadratic detection
Pulse compression	Barker, complementary, and Spano codes

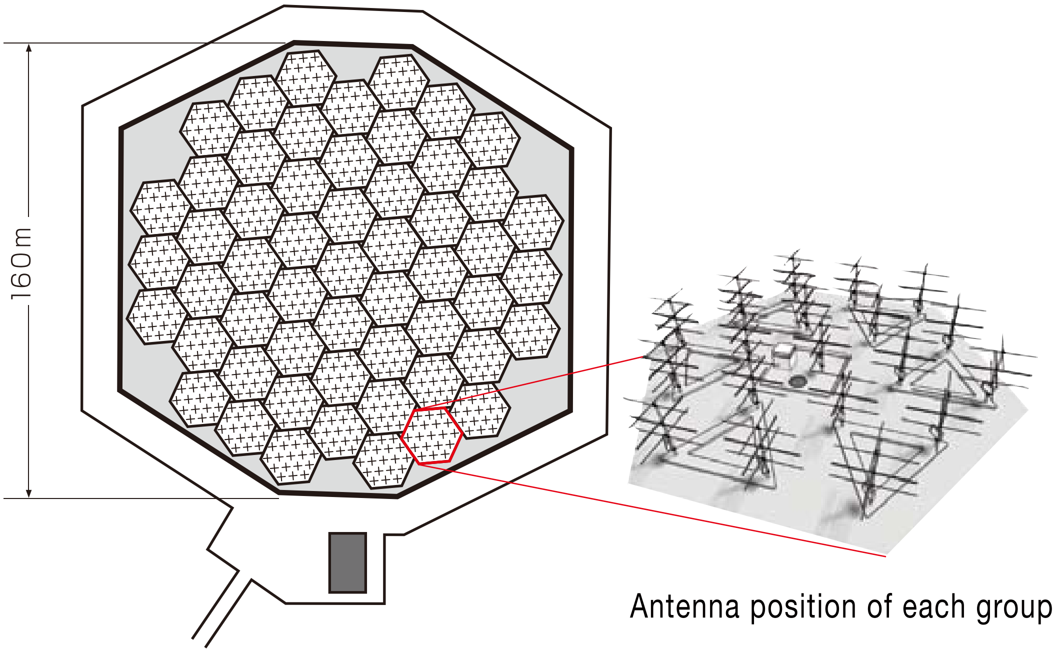

Figure 5: The EMU radar antenna array. Each cross represents the location of a three-element Yagi antenna and TR module.

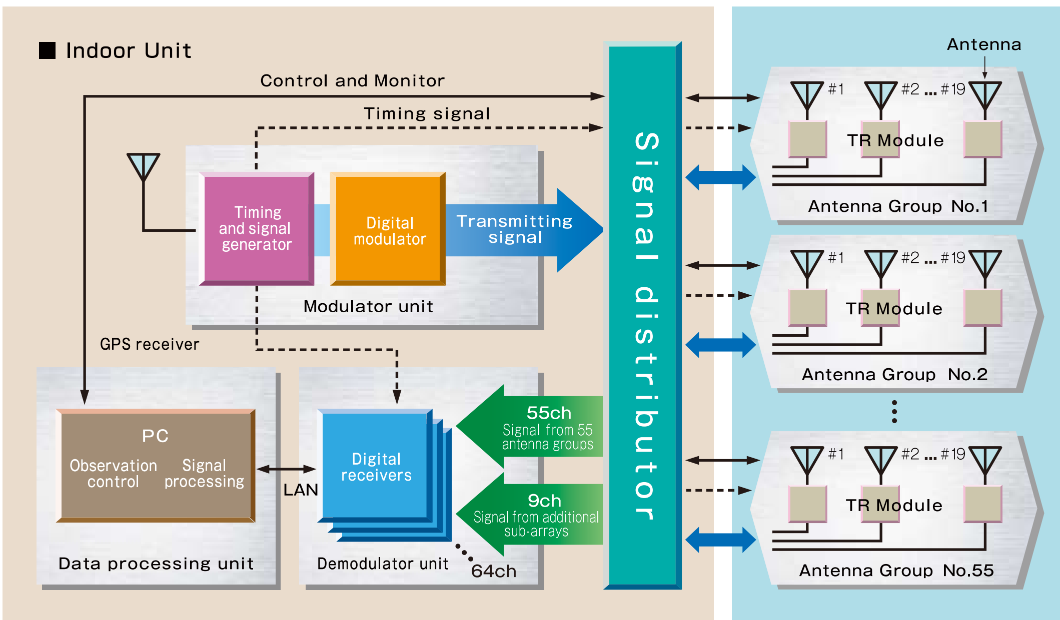

Figure 6: Schematic diagram of the EMU radar.

6. Global Observation Network and the EMU Radar

Figure 7 shows global distribution of IS and MST radars. The IS radar has a long history of more than 50 years [Robinson et al., 2009; Altschuler and Salter, 2013]. Arecibo and Jicamarca radars were constructed as constant facility for the IS experiment in early 1960s. Then development of the MST radar followed [VanZandt, 2000]. The EISCAT radar started multi-static IS observations in 1981 [Schlegel and Moorcroft, 1989]. The MU radar was the first MST radar with the active phased-array which most recent radars are using [IEEE Milestone for the MU radar, 2015]. It is very clear that the current solar-terrestrial physics is developed, on many aspects, based on countless results from their observations [e.g., Kelley, 2009; Fukao and Hamazu, 2013]. The EMU and the EISCAT_3D radars that we propose from our project should help expansion of the science. These two radars will further promote international collaboration of the IS and MST radars complementing the existing facilities, such as Resolute Bay (74.7N, 94.9W), Sondrestrom (67.0N, 50.9W), Poker Flat (65.1N, 147.5W), Millstone Hill (42.6N, 71.5W), the MU radar (34.9N, 136.1E), Arecibo (18.3N, 66.8W), Indian MST radar (13.5N, 79.2E), Jicamarca (12.0S, 76.9W) and PANSY (69.0S, 39.6E).

The EMU radar should work with this global observation network of the IS and MST radars. In particular with the MU radar (in Japan, mid-latitude region), PANSY [Sato et al., 2014] and EISCAT_3D radar (in polar region) are important, and contribute to the study of the coupling processes in the solar-terrestrial system. Help from the regional network observations is also important for our studies. In the southeast Asian region, we already have observation network of ionosondes, meteor and MF radars, airglow imagers, magnetometers, etc. EAR was already successful on collaboration with Indian MST radar or Sanya radar in China [e.g., Patra et al, 2008; Li et al., 2013]. Observation network in the Asian sector is now rapidly growing. For example, IS experiment recently started at Quijing, China (25.6N, 103.8E, [Ding et al., 2014]), which research activity seems limited but close to the geomagnetic conjugate to our EMU/EAR site. We can anticipate fruitful studies between the EMU radar and these regional and global network of instruments.

During the planned period of this project in 2016-2025, several scientific satellite missions will be launched, such as Exploration energization and Radiation in Geospace (ERG) (http://ergsc.stelab.nagoya-u.ac.jp/index.shtml.en) [Miyoshi et al., 2012], Ionosphere Connection Explorer (ICON) (http://dev.icon.ssl.berkeley.edu/) [Rider et al., 2015], and Constellation Observing System for Meteorology, Ionosphere and Climate 2 (FORMOSAT-7/COSMIC-2) (http://www.cosmic.ucar.edu/cosmic2).

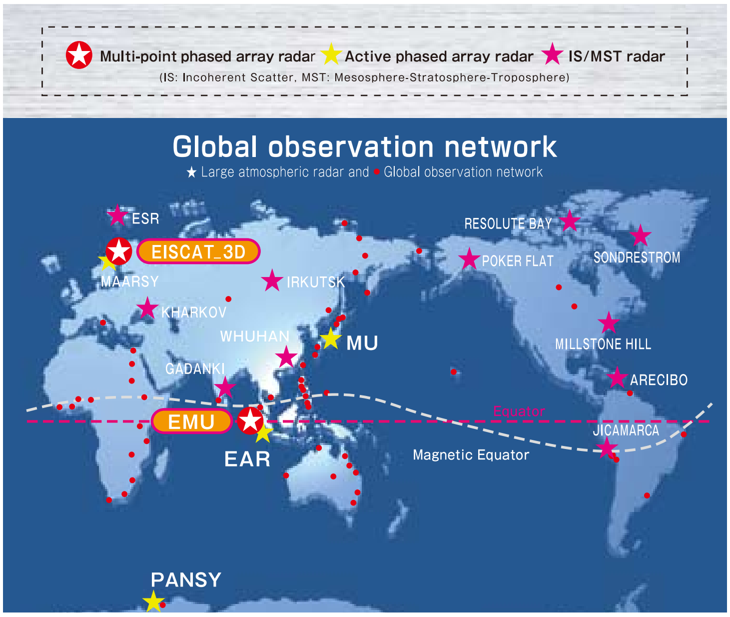

Figure 7: Map of the possible sites for the global observation network.

7. Data Exchange System

Effective database construction is also an essential part to make such a comprehensive network observation available. Our group has constructed ground-based observation database under the project "Inter-university Upper atmosphere Global Observation NETwork (IUGONET)" since 2009 [Hayashi et al., 2013]. The concept of the IUGONET is illustrated in Figure 8. The IUGONET project has archived metadata of various ground-based observation instruments operated by five Japanese institutions, i.e., Tohoku University, National Institute of Polar Research, Nagoya University, Kyoto University, and Kyushu University. Under the IUGONET project, huge amount of various dataset obtained by these institutions are recorded into the database, and their metadata (catalogue information) can be searched on the web. Comprehensive data analysis using different types of data becomes possible by using this database [Abe et al., 2014]. A unified data analysis tool, called IUGONET data analysis software (UDAS) [Tanaka et al., 2013], was also developed to make plots of the real data in the database. Such a construction of metadata database with unified data analysis tool is essential for the proposed mission of global network observations, in order to make use of the advantage of the network observation and to expand the scientific use of the data. The unified data analysis tool also encourages the data analysis for scientists at developing countries and students who are not familiar to the different types of data handling [Hayashi et al., 2013].

RISH accumulates various data from our studies, and form them as Humanosphere database. The data are basically open to the research community. We now plan to make a backup site in Indonesia to hold the copy of all data in safe. The copy database system will be open to the Indonesian research community, and will be helpful for future expansion of science in Indonesia.

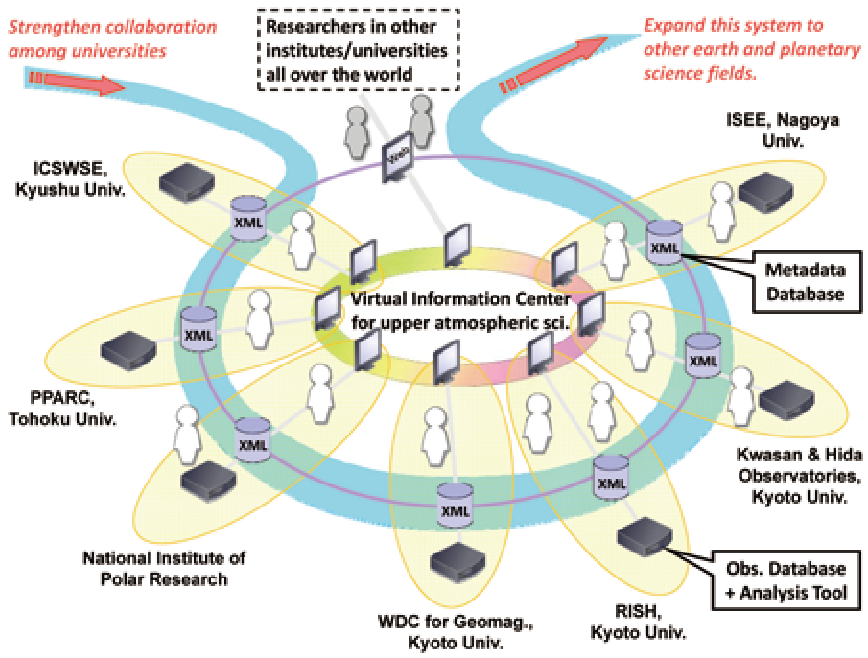

Figure 8: Schematic view of the virtual informetion center of the IUGONET project. A meradata database is distributed at the IUGONET institutes, as shown with boxes labeled "XML", and connected to others through the Internet in order to share all the metadata. In addition, data analysis software to handle various kinds of data is developed (Modified from Hayashi et al. [2013]).

8. Capacity Building

Collaboration between RISH and LAPAN has been very successful in terms of education and capacity building. All Ph.D. degrees obtained based on the EAR-related studies is 16, which includes 5 Ph.D. degrees obtained by Indonesian students. Now RISH has two Indonesian Ph.D. course students visiting from LAPAN. Number of master degrees is 43 that include 6 Indonesian and 1 Malaysian students.

Efforts for capacity building have been continuously conducted. Kyoto University obtained the 21st century Center of Excellence (COE) program KAGI21[1] in FY2003-FY2007, and hold KAGI21 International Summer School for four times at ITB in Bandung. Indonesian researchers participated in the school for learning recent research topics of geosciences. RISH has been awarded other funds for the capacity building. Examples are Asia-Africa Science Platform Program by Japan Society for Promoting Science (JSPS) "Elucidation of ground-based atmosphere observation network in equatorial Asia" (FY2008-FY2010), JSPS Exchange Program for East Asian Young Researchers "Fostering Program of Leading Young Scientists toward the Establishment of Humanosphere Science in East Asia" (FY2009-FY2010), and JSPS-LIPI Joint Research Project "Japan-Indonesia collaborative study of vertical coupling of the equatorial atmosphere with large atmospheric radars" (FY2014-FY2016). All these funds were used for the capacity building by lectures in Indonesia, cooperative observations/studies, invitation of Indonesian researchers to scientific meetings in Japan, etc. RISH holds Humanosphere Science School (HSS) in Indonesia in the yearly basis, which also helps to enhance the science of the humanosphere.

9. Summary and Conclusion

Japan and Indonesia scientific collaboration on the study of the equatorial atmosphere started in the middle 1980s. RISH and LAPAN were the primary institutions for the collaboration. In Indonesia, other institutions like BPPT, BMKG, and ITB joined the research as well. In 2001 the EAR started operation under this collaboration, and was successful for long-term continuous observations until today. RISH is now promoting a large research project "Study of the coupling processes in the solar-terrestrial system". One dominant process of the solar energy is the solar radiation that is maximum in the equatorial region. We will study responses to the solar energy input in the magnetosphere, ionosphere, middle atmosphere and troposphere. RISH and LAPAN are planning to install the Equatorial MU (EMU) radar, aiming to study and capture the energy and material flow occurring in all height ranges of the equatorial atmosphere — a phenomenon known as the equatorial fountain. We will expand international collaboration on ground-based observation network of IS/MST radars and other instruments. The observed results will be archived in a database, which will be widely opened to international community by utilizing a metadata exchange system – IUGONET. We also pursue capacity building of the younger researcher under our collaboration. RISH and LAPAN will continue this successful scientific collaboration for long, benefit from our research, and contribute to the Earth's environmental studies.

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[1] KAGI21 is an abbreviation of Kyoto University Active Geosphere Investigation for the 21st Century COE program.

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Research Institute for Sustainable Humanosphere (RISH)
Kyoto University, Japan

National Institute of Aeronautics and Space (LAPAN)
Indonesia