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Abstract.

In this report, a newly-developed lightning observation network system is outlined. The network consists of an optical observation site (Padang in Indonesia) and three electromagnetic observation sites (Pontianak in Indonesia, Tainan in Taiwan, and Saraburi in Thailand). At Padang site, a small low-light CCD camera was installed to observe the optical emission of lightning flash. On the other hand, a monopole, a dipole, and a set of orthogonal loop antennas were installed at each site to detect electromagnetic waves in the frequency range of 0.1-40 kHz. The obtained data are analyzed to monitor lightning activity in Southeast Asia in various spatiotemporal scales and clarify severe weather phenomena which cause significant damages on the human activity.

1. Introduction

Recent satellite-based optical measurements have clarified the global distribution of lightning and their related phenomena such as transient luminous events (TLEs: sprites, elves, blue jets). As shown in Figure 1, the Optical Transient Detector (OTD) on the MicroLab-1 satellite carried out the first long-term observations and found the highest lightning activity in Central Africa, North and South America, and Southeast Asia [*Christian et al.*, 2003]. More recent optical measurements with the Imager for Sprites and Upper Atmospheric Lightning (ISUAL) on the FORMOSAT-2 satellite clarified the global distribution of transient luminous events (TLEs: sprites, elves, and blue jets) [*Chen et al.*, 2008] that are lightning-produced electrical discharges occurring in the middle and upper atmosphere. The obtained data indicated that the Indian Ocean and the central Pacific Ocean were additional active regions of lightning and TLEs in the midnight condition. Thus, it is clear that Southeast Asia is one of the most important regions to investigate lightning activity and their effects in the middle and upper atmosphere. From

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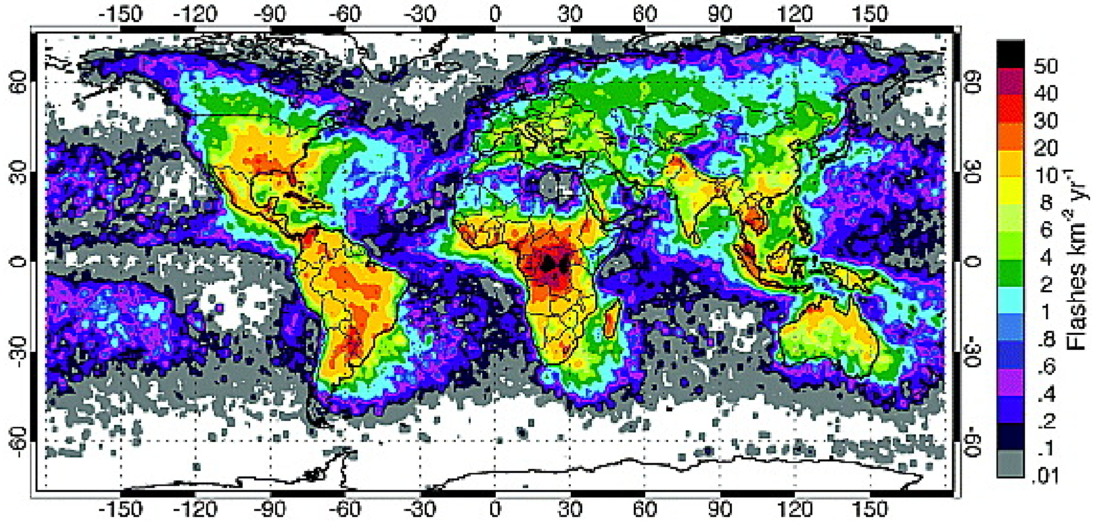


Figure 1. Global distribution of lightning flash observed by the OTD instrument onboard the MicroLab-1 satellite [*Christian et al.*, 2003].

a social viewpoint, the continuous monitoring of lightning discharge is also an essential issue because it is a direct indicator of severe storms that cause significant damages on the human activity. However, the spatial and temporal characteristics of lightning in Southeast Asia remain open questions and the development of observation network system is still an urgent task.

2. Scientific Objectives

Lightning discharges often induce strong electromagnetic fields and drive various types of electrical phenomena in the atmosphere, ionosphere, and magnetosphere (see Figure 2). In order to understand their eletrodynamic coupling processes, a lightning observation network system is under construction in Southeast Asia. Here, major scientific objectives that the system would bring remarkable progress on our understanding are summarized.

2.1 Troposphere: Thunderstorm and Lightning

Past lightning observations have primarily been carried out in the mid-latitude regions where the most developed countries are situated. By using National Lightning Detection Network (NLDN) and meteorological observation systems in USA, the critical meteorological parameters that are strongly correlated with the occurrence of lightning have gradually been clarified. Lightning forecast techniques developed on the present observational facts, however, still have significant errors and do not yet reach a practical level. It is largely because the coupling process between the thermodynamics which

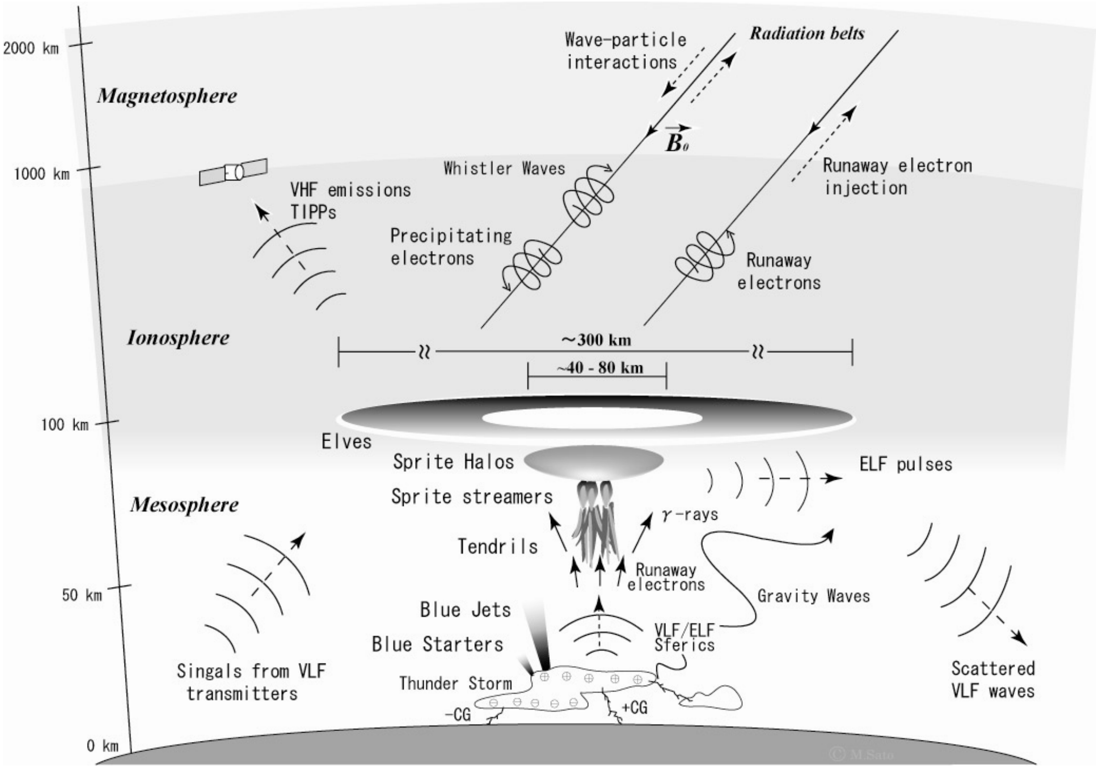


Figure 2. Various types of lightning-related phenomena occurring in the atmosphere, ionosphere, and magnetosphere [courtesy of *R. Miyasato, Tohoku University*].

governs the development of thunderstorm and the electrodynamics which determines the occurrence of lightning is not yet fully understood. It is therefore essential to coincidently carry out lighting and thunderstorm observations in the equator region where meteorological conditions are totally different from the mid-latitude region. For example, coordinated observations with the HARIMAU (Hydrometeorological ARray for Isv-Monsoon AUtomonitoring) project of JAMSTEC (Japan Agency for Marine-earth Science TEChnology) and the EAR (Equatorial Atmosphere Radar) observation system of Kyoto University would be beneficial to understand three-dimensional meteorological conditions (wind fields, precipitation structures) at the occurrence of lightning. Furthermore, by comparing with satellite-based meteorological data, it is possible to clarify lightning activity in larger cloud systems such as Madden-Julian oscillations, tropical cyclones, and mesoscale convective complexes.

2.2 Middle/Upper Atmosphere: Sprites, Elves, and Jets

Transient luminous events (TLEs) such as sprites, elves, and blue/gigantic jets are high-altitude air discharges, which are the manifestation of lightning-driven electrical coupling between the troposphere and the lower ionosphere [*Fullekrug et al*., 2006 and references cited therein]. Recent optical measurements with the FORMOSAT-2 satellite clarified that the occurrence frequency of TLEs in Southeast Asia is much higher than those expected in the past [*Chen et al.*, 2008]. One of the most prominent features of TLEs in this region is that elves are produced more frequently than sprites. Although both phenomena are induced by lightning discharges, their driving forces are different: quasi-static electric fields (QE-fields) for sprites and electromagnetic pulses (EMPs) for elves. Therefore, the fact that elves are frequently produced in Southeast Asia suggest that the derivative of lightning electric current tends to be higher and, consequently, stronger EMPs tend to be radiated in this region. The VLF (Very Low Frequency) network system developed in the present study would, for the first time, provide us the electrical properties (polarity, current moment changes, etc) of Asian lightning. And coordinated observations with several ongoing and upcoming satellite projects (ISUAL, Sprite-sat, ISS/ASIM, ISS/GLIMS, TARANIS) would make remarkable progresses on our understanding about the coupling process between lightning and TLEs.

2.3 Ionosphere: Transient Perturbations

Sometimes, VLF electromagnetic waves which travel along the Earth's waveguide between the ground and ionosphere are significantly modulated both in phase and amplitude. Such perturbations were discovered in the middle of twentieth century and their characteristics and generation processes were extensively studied [e.g., *Sampath et al.*, 2000]. It is now broadly accepted that lightning discharge is a primary production source of such perturbation. A part of lightning-induced electromagnetic waves in the Whistler mode travels upward along the magnetic field line and precipitates the electrons of radiation belts via wave-particle interactions. The precipitated electrons hit and perturb the ionosphere and eventually cause significant modulation on the electromagnetic waves that are propagated between the ground and lower ionosphere. In addition to such an indirect effect, lightning-induced electromagnetic waves can also directly perturb the lower ionosphere, which is sometimes able to see as the optical emission of elves. The observations of VLF perturbations were so far primarily carried out in the mid-latitude region. Therefore, the simultaneous monitoring of lightning and ionospheric perturbations in the low-latitude region is valuable, because the dip angle of geomagnetic field is close to zero and the conditions of wave-particle interaction is clearly different from those in the mid-latitude region.

2.4 Magnetosphere: Radiation Belts and Terrestrial Gamma-ray Flashes

It is believed that lightning discharges play an important role in producing and reducing the electrons of inner magnetosphere. The primary reduction process is electron precipitation caused by interactions with lightning-induced Whistler waves. On the other hand, the primary production process is the upward-going runaway electrons which are accelerated by the lightning-induced quasi-electrostatic field. In recent years, terrestrial gamma-ray flashes (TGFs) that would be relevant to the acceleration of runaway electrons in the Earth's atmosphere were discovered. It was an extremely surprising phenomenon since gamma-rays had primarily been observed in high-energy astronomical processes such as supernova explosions. The CGRO/BATSE instrument for the first time detected gamma-rays which escaped from the Earth and, subsequently, the RHESSI satellite found that their occurrence locations corresponded to the active regions of lightning discharge [*Smith et al.*, 2005]. The obtained observational facts suggest that TGFs are produced by bremsstrahlung associated with lightning. However, specific generation processes are not yet fully understood and the coincident observations of lightning, TLEs, and TGFs would give us one of the most essential solutions. The system written in this paper can carry out such comprehensive observations by cooperating with the satellite projects written in the last part of subsection 2.2.

3. System Specifications

Lightning discharges radiate a broad spectrum of electromagnetic waves, which can be propagated in the Earth's waveguide between the ground and lower ionosphere. The travelling distance depends on the frequency and the radio waves in the VLF range (a few to a few tens of kHz) can be propagated up to 10,000 km away from the source lightning location. By measuring atmospherics (electromagnetic waves in the frequency range from a few to a few tens of kilohertz) in the VLF range at several observation sites, it is possible to monitor lightning activity occurring all over Southeast Asia. At the same time, it should be noted that the measurements of VLF radio waves enable us to detect the vertical component of lightning, or cloud-to-ground lightning, only. On the other hand, optical sensors can detect all types (cloud-to-ground, intra-cloud, and cloud-to-cloud) of lightning discharges that occur within a distance of a few hundreds of kilo meters. Therefore, it provides essential information on the total electrical activity of thunderstorm system. In summary, simultaneous radio and optical observations enable us to comprehensively study the activity of lightning in Southeast Asia in a various spatial scales from single thunderstorm system to mesosclale convective complex. The observation sites that constitute the network system are shown in Figure 3. Hereafter, the specifications of optical and electromagnetic system are described in details.

3.1 Optical observation system

In order to monitor lightning activity in single thunderstorm system, a low-light CCD camera system was installed in Padang, West Sumatra, Indonesia. As shown in Figures 4 and 5, MIA (Minankabau International Airport) X-band Doppler radar site of JAMSTEC is located in Padang as one of the observatories of HARIMAU project. About 75 km

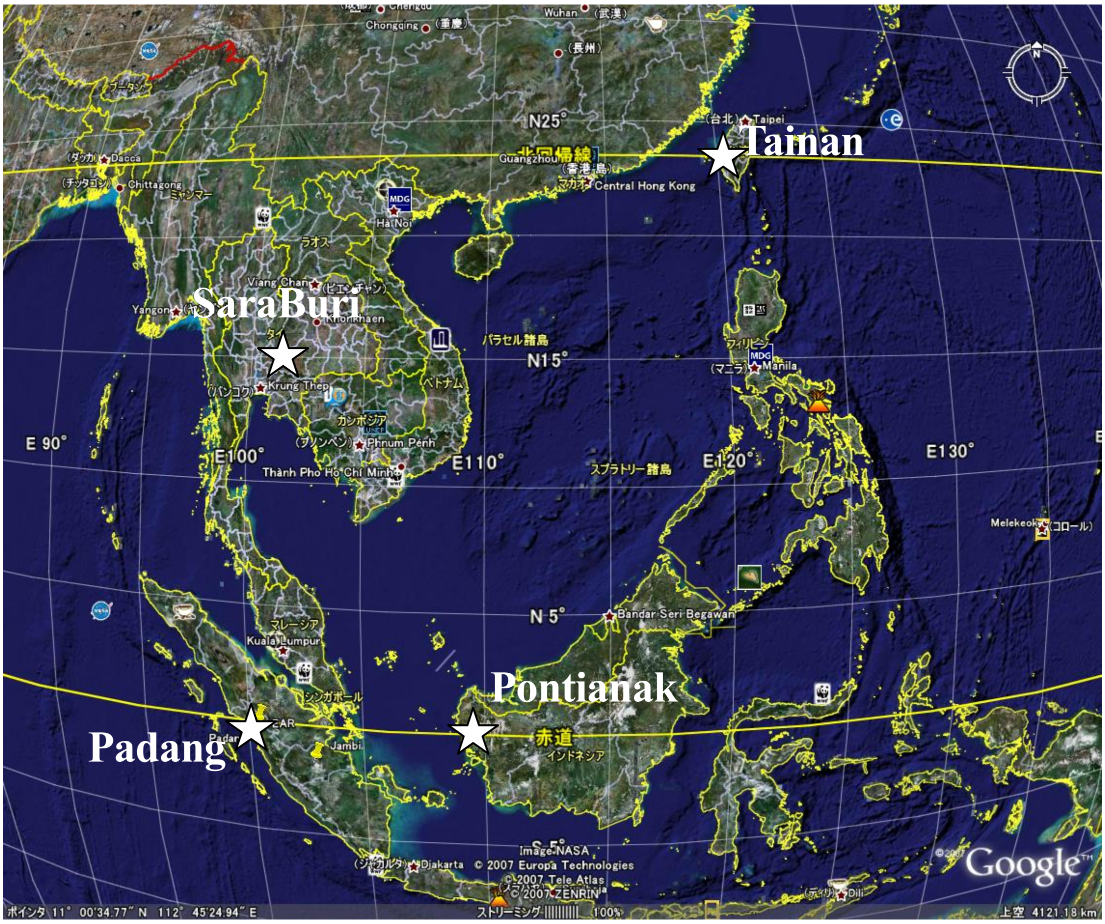


Figure 3. An overview of VLF observation network system. It consists of an optical observation site (Padang in Indonesia) and three VLF radio observation sites (Tainan in Taiwan, Saraburi in Thailand, and Pontianak in Indonesia).

north from the site, the EAR system of Kyoto University is also located. Thus, Padang site is one of the most suitable observatories to carry out lightning observation in cooperation with meteorological radar measurements. At this site, an X-band Doppler radar, an automatic weather station, and a sky-view camera are operated continuously and the obtained data are collected by a recording system installed in a container. A lightning camera used in the present study was fixed on the roof of the container and is directed to the sky above the EAR site (azimuth: 5 degrees west from the geographical north, elevation: 30 degrees up from the local horizon). The specifications and block diagram of observation system installed at Padang site are shown in Table 1 and Figure 6, respectively. By using a non-spherical lens which has an automatic aperture-adjuster that is synchronized to the CCD output level, the imaging system can be continuously operated both in day and night time. The output image from a CCD camera is stamped with precise time by a GPS time inserter. The stamped images are subsequently converted

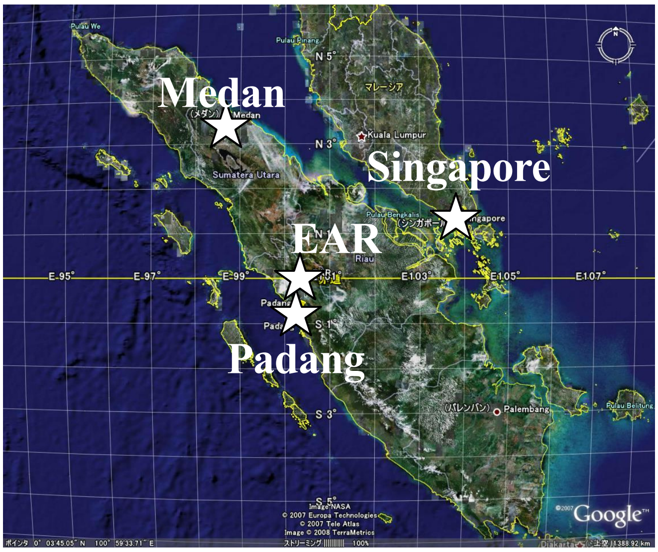


Figure 4. The location of Padang site. It is situated 75 km south of Equatorial Atmosphere Radar of Kyoto University.

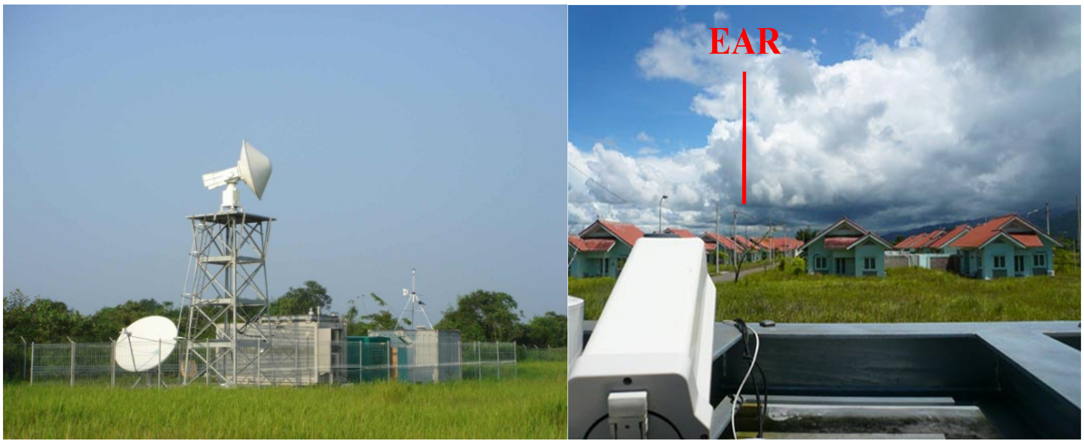


Figure 5. Photos of (left) the MIA X-band Doppler Radar at Padang site and (right) the CCD camera that was fixed on the roof of an observation container.

Table 1. Specifications of optical observation system that consists of a camera lens, CCD device, GPS time inserter, and HDD video recorder.

Lens M/N	CBC: 6mm/F0.8	GPS Timer M/N	FOR.A: VTG-15
CCD M/N	WATEC: WAT-902H2 ULTIMATE	HDD Recorder M/N	AVTECH: AVC783 (500GB)
Field-of-View	57 deg (h) x 43 deg (v)	Time Accuracy	1/100 s
Pixel Size	768 (h) x 494 (v)	Recording Format	MPEG-4
Exposure Time	1/60 – 1/100,000 s	Repetition Time	30 fps

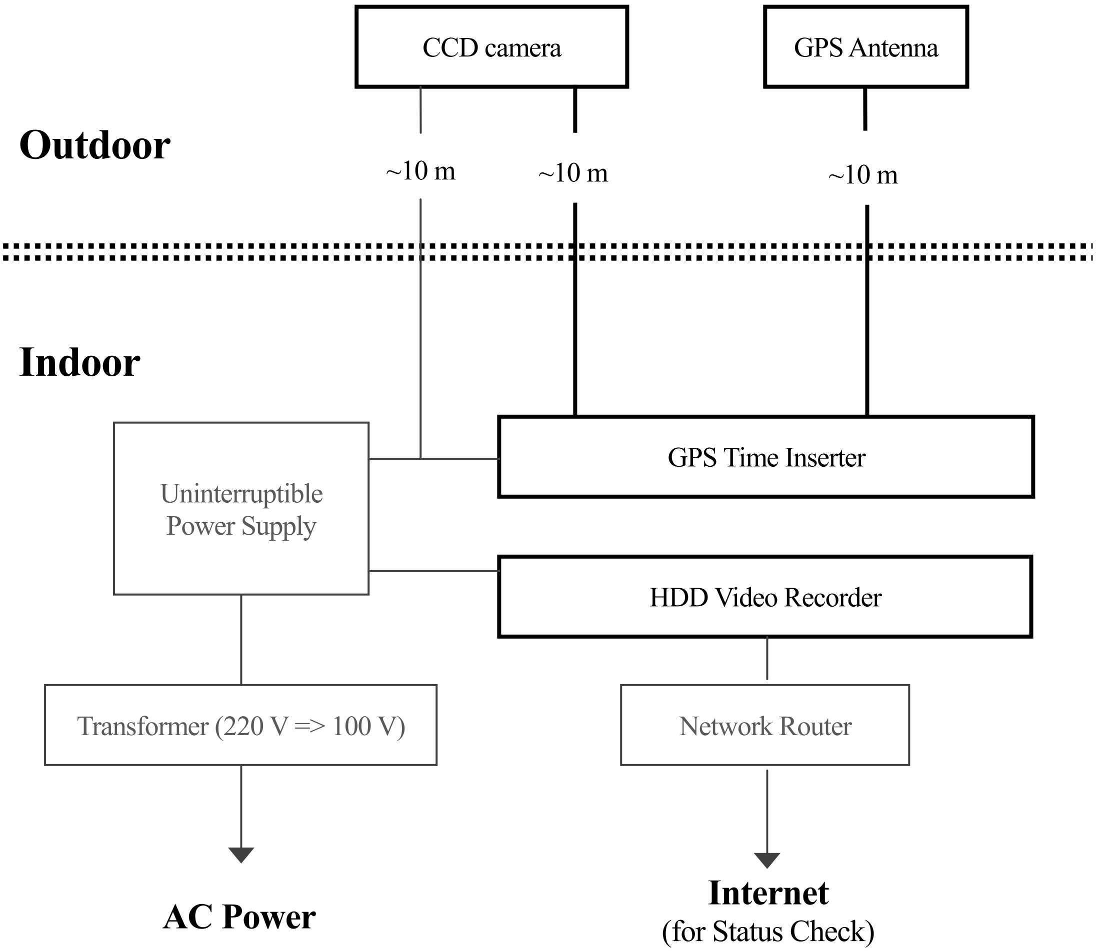


Figure 6. A block diagram of optical observation system installed at Padang site. A CCD camera and a GPS antenna are located outdoor while a GPS time inserter and a HDD video recorder are located indoor.

to the MPEG-4 compression format and recorded by a HDD video recorder with a normal video frame rate of 30 fps. A storage space of 500 GB realizes the continuous monitoring of lightning flash during several months. In addition, by using a trigger recording mode, the system can record the images that exceed certain preset trigger criteria. In such a case, data amount would be significantly small compared with the continuous observation mode and, therefore, the system can record lightning images with maintenance-free for nearly 1 year. The data recorder is connected to the internet so that one can check the system status and change the observation mode from anywhere in the world.

3.2 VLF radio observation system

As shown in Figure 3, three sites were selected as VLF observatories in terms of noise level, infrastructures, and accessibility. The first site is Tainan observatory (23.08º N, 121.1º E) in Taiwan which is located a few tens of kilo meters away from the centre of Tainan city. The second site is Saraburi observatory (14.53º N, 101.0º E) in Thailand which is an area of Chulalongkorn University and is located ~100 km away from Bangkok city. The third site is Pontianak observatory (0.0ºN, 109.4º E) in Indonesia which is one of the LAPAN observatories and is located a few tens of kilo meters away from the centre of Pontianak city.

At each site, a set of orthogonal loop antennas is used to measure the magnetic-field (N-S and W-E) components of atmospherics induced by lightning discharges. On the other hand, a dipole and monopole antennas are used to measure the vertical electric-field component of electromagnetic waves radiated by lightning and artificial transmitters, respectively. The photos and block diagram of the observation system installed at each site are shown in Figures 7, 8 and 9. The output signals from antennas are amplified by a pre amplifier and a main amplifier and, subsequently, recorded by three personal computers (PCs) together with GPS time code signals (see Table 2). The first computer (PC1) is used for the monitoring of lightning and the second (PC2) and third (PC3) computers are used for the monitoring of lower ionosphere. PC1 records the waveforms of lightning atmospherics in both electric and magnetic field components only when the signal exceeds certain pre-programmed trigger criteria. At the present configuration, the sampling frequency of Analog/Digital (A/D) converter is 100 kHz and the recording duration is 2 seconds, which can be adjusted depending on observation targets. Because the temporal resolution is sufficiently high, the obtained data enables us to derive the occurrence location and time of source lightning with accuracies of 10 km and 10 μs, respectively. Furthermore, since the system covers a broad frequency range of 1-40 kHz, it is possible to derive the current moment change of lighting that is an essential parameter for the production of TLEs [*Adachi et al*., 2008]. PC2 records a 2-minute magnetic-field data of lightning-induced tweek atmospherics every 10 minutes. The observation frequency range is from 100 Hz to 10 kHz and the dynamic spectrum is continuously recorded during the scheduled time slot. From the obtained spectral data, it is possible to estimate the equivalent altitude of certain electron density in the D-region ionosphere that is often perturbed by electrons precipitated from the inner magnetosphere and the cosmic rays such as gamma ray bursts/flares. PC 3 records the vertical electric field component of radio waves emitted from artificial transmitters. Such transmitter signals are commonly used for the purpose of navigation and time synchronization in many countries. PC3 samples radio waves with an A/D conversion frequency of 200 kHz and, by analyzing the real-time data, records the power and phase of several transmitter

Figure 7. Photos of a system installed at each site. (Left) Monopole and Dipole antennas used for the electric-field measurements. (Center) A set of orthogonal loop antennas used for the magnetic-field measurements.

Figure 8. A main amplifier and data recording systems installed inside a room.

Table 2. Specifications of VLF observation system. It consists of three computers to monitor lightning discharges and ionospheric perturbations in Southeast Asia.

	Dipole Antenna	Orthogonal Loop Antennas		Monopole Antenna
Observation target	E-field of lightning atmospherics	B-field of lightning atmospherics		E-field of standard-time radio waves
Size of ant. Element	2 m length	1 m x 1m square		2 m length
Obs. Frequency	1-40 kHz	100 Hz - 40 kHz	100 Hz - 10 kHz	40,60 kHz etc
Recording system	PC 1 (Desktop)		PC2 (Desktop)	PC3 (Laptop)
Sampling	100 kHz, 16-bit resolution		20 kHz, 16-bit	200 kHz, 16-bit (10 Hz record.)
Data amount	~500 GB/year (4 MB/record)		215 GB/year	15 GB/year
Power	Average: ~400 W (max: 800 W)			

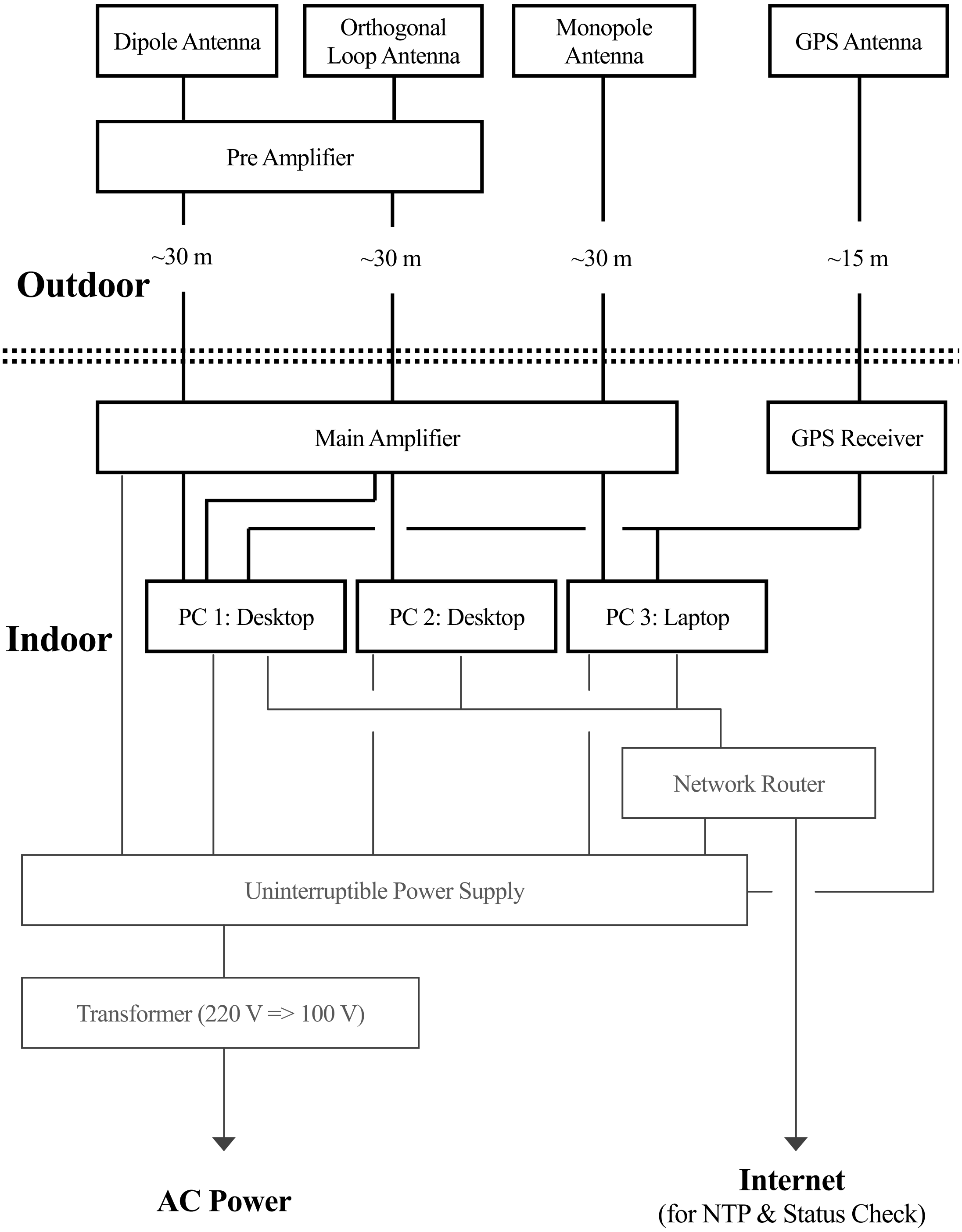


Figure 9. A block diagram of VLF recording system installed at each site. The antennas and pre amplifiers are located outdoor and main amplifiers and recording systems are located indoor. The GPS time code signal enables to record precise event time which is essential for the estimation of lightning occurrence position.

signals at a rate of 10 Hz. The obtained data are used for the monitoring of D-region ionosphere often perturbed by the electron precipitations associated with the magnetic storms and the lightning-induced Whistler waves.

4. Sample Data

Sample data obtained by the present observation system are described in this section. Figure 10 represents two examples of lightning flashes observed by CCD camera installed at Padang site in Indonesia. The left image was captured at 14:00:45 UT (Universal Time) or 21:00:45 LT (Local Time) on 29 January 2008 while the right image was captured at 14:13:56 UT (21:13:56 LT) on the same night. In both images, bright optical emissions of cloud flash illuminated by lightning are clearly seen in the lower portions. By comparing the azimuths of bright emissions in these figures, it is clear that the occurrence location of source lightning moves from left to right with time. This is because their parent thunderstorm moves eastward, which corresponds to rightward in the camera images. Figure 11 shows the temporal variation of lightning occurrence frequency on this night. From the beginning of observation at 12:30 UT (19:30 LT), lightning occurrence frequency increased continuously and reached a maximum value of 7.3 flashes/minute at ~13:00 UT (~20:00 LT). After the peak, lightning activity decreases and eventually ended at ~15:00 UT (~22:00 LT). From this one-night observation, it is found that the time scale of lightning activity corresponds to the typical life time of a cloud cell, suggesting an isolated thunderstorm was the producer of lightning.

Figure 12 represents an example of lightning event detected by a vertical dipole antenna and a set of orthogonal loop antennas. The left figures show (from top to down) the electric field, east-west (E-W) magnetic field, north-south (N-S) magnetic field, and GPS IRIG-B time code signal, respectively. In this case, all data was sampled at a rate of 100 kHz and recorded for 2 seconds around the trigger time by using the electric field signal as a trigger reference channel. A Lissajous plot which represents the ratio of N-S and E-W magnetic field components is shown in the right figure. A dotted (not dashed) line represents the azimuth direction of parent lightning that best fits the data. In a similar manner, by measuring the directions of VLF radio waves simultaneously at three sites, the locations of parent lightning can be estimated as represented by red lines in Figure 13. This technique is referred to as the magnetic-direction-finder (MDF) method and used in major lightning detection network systems such as the NLDN [*Rakov and Uman*, 2003]. However, the precision of lightning location depends on the accuracy of azimuth determination at each site, and the azimuth accuracy depends on the installation precision of orthogonal loop antennas in addition to the linearity of lightning atmospherics. Consequently, the typical estimation error of azimuth direction is several degrees, which

Figure 10. Sample data of lightning flash observed at (left) 14:00:45 UT and (right) 14:13:56 UT on 29 January 2008. Bright optical emissions found in the lower portion of each image are the cloud illumination by lightning flash.

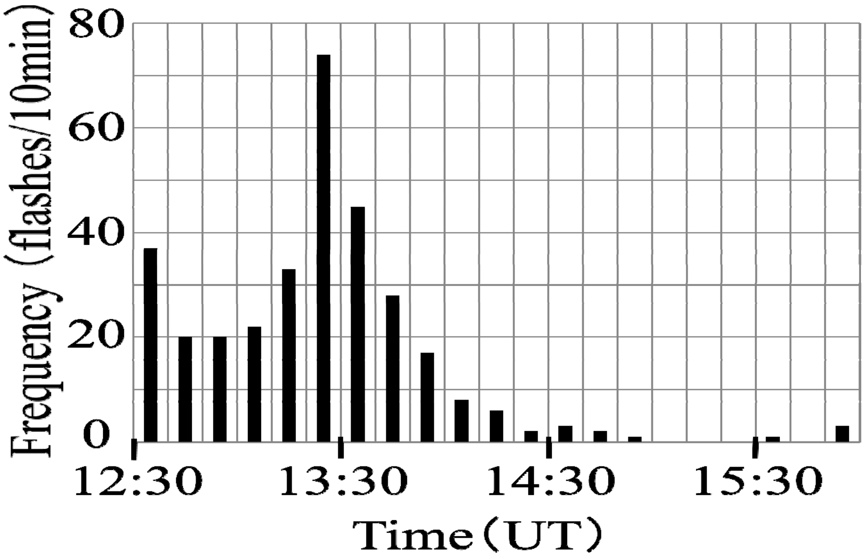


Figure 11. Temporal variation of lightning activity on 29 January 2008. The observation was started at 12:30 UT (19:30 LT) and ended at 16:00 UT (23:00 LT). The maximum frequency of 73 flashes per ten minutes is found at ~13:30 UT (~20:30 LT).

eventually leads to an lightning positioning error of >100 km at a location near Pontianak site (~2800 km and ~1800 km from Tainan and Saraburi sites, respectively) in the present VLF systems. In order to improve the positioning accuracy, it is preferable to combine the MDF method with the time-of-arrival (TOA) method as shown by blue lines in Figure 13. In the TOA method, differences in the arrival time of lightning atmospherics at three sites

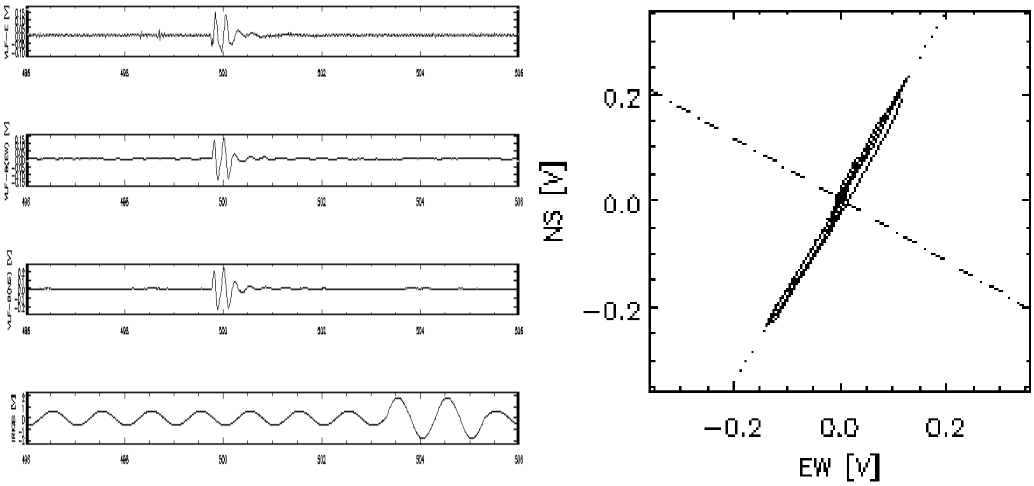


Figure 12. An example of lightning-induced atmospherics observed by orthogonal loop antennas. (Left) The electric field and magnetic field (E-W and N-S) components of lightning atmospherics and GPS IRIG-B time code signal. The horizontal axis represents the time from the beginning of data recording in the unit of millisecond. (Right) Lissajous plot calculated from magnetic field data. The direction of data indicates the azimuth of parent lightning discharge.

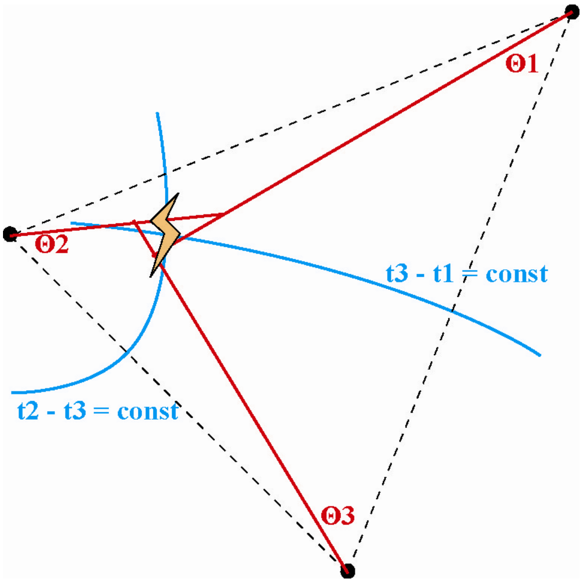
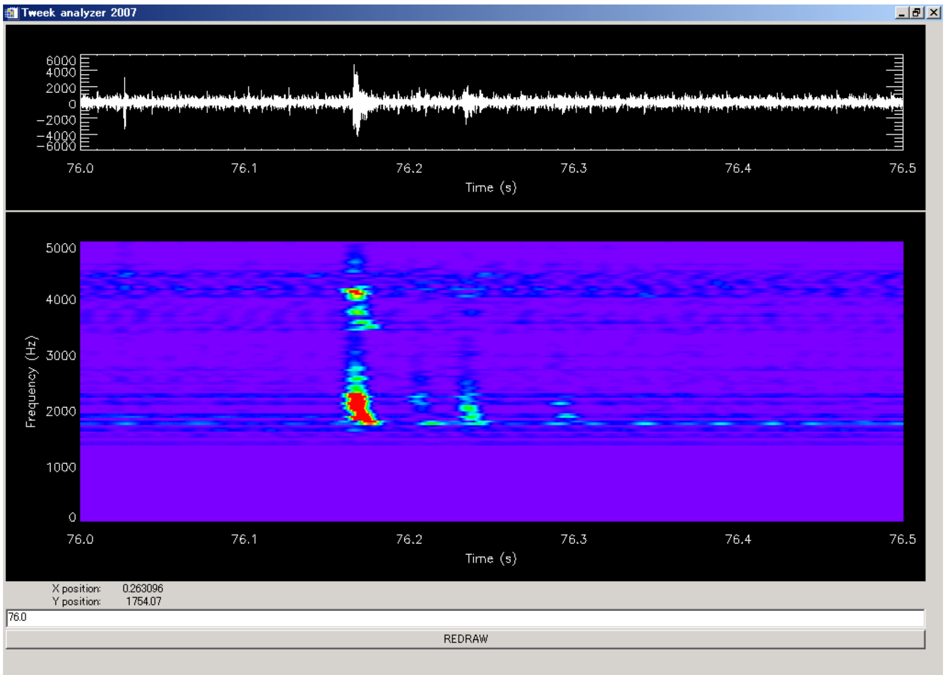


Figure 13. A schematic representing the method to estimate the occurrence position of parent lightning using VLF observation network system. Red lines represent azimuth directions of electromagnetic wave observed at each site. Blue lines represent hyperbolas where the differences of arrival time between two observation sites are constant.



X position: 0.263096
Y position: 1754.07
76.0

Figure 14. Tweek atmospherics observed at 16:51:16 (UT) on 13 January 2008 at Tainan site in Taiwan. (Upper) Magnetic field fluctuations represented in the time domain. (Lower) Dynamic spectrum calculated by the fast Fourier transform method. Two largest tweeks are seen at 76.18 (s) and 76.24 (s), respectively.

are used to determine the location of parent lightning. Each blue line in Figure 13 shows a hyperbola at which the difference of radio arrival time observed at the selected two sites is constant. And the crossing point of two blue lines corresponds to the solution of parent lightning location. The combination of MDF and TOA methods enables us to determine the location with a precision better than 10 km.

Figure 14 represents a sample data of tweek atmospherics recorded by PC2. Two clear tweeks can be seen at 76.18 s and 76.24 s, respectively. In general, tweek atmospherics are observable in fall, winter, and spring seasons. Since typical occurrence frequency is 100-200 events per minute, it is expected to observe as much as 1-3 events during a 2-minute recoding window by the PC2 system. As tweek atmospherics travel in the Earth’s waveguide, they gradually contain considerable dispersions, which reflect the boundary condition in the lower ionosphere. Therefore, by analyzing the spectrum of tweek atmospherics, it is possible to estimate the ionospheric reflection height (where the electron density is 20-28 /cm3) and the distance to source lightning location. In the case of Figure 14, the reflection height and propagation distance of first event were estimated to be 89.40 km and 1603 km, respectively. And those of second event were estimated to

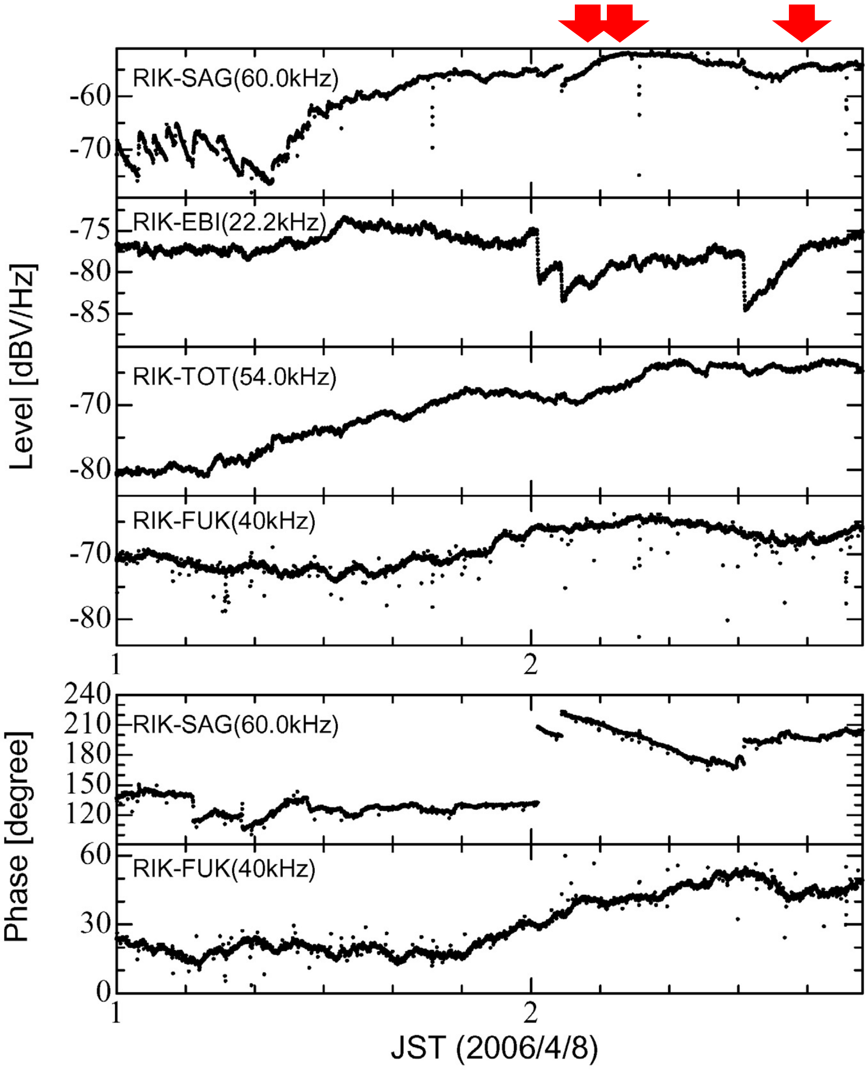


Figure 15. Perturbations on transmitter signals observed at Rikubetsu observatory (RIK) in Japan. Upper four panels show amplitude fluctuations while lower two panels show phase fluctuations. Notations shown in each figure represent the locations of receiver and transmitter and the frequency of transmitted radio waves. Here, SAG, EBI, TOT, and FUK stand for the call signs of each transmitter located in Saga, Miyazaki, Kanagawa, and Fukushima prefectures, respectively. Red arrows show the time when significant perturbations are found on the RIK-SAG and RIK-EBI signals.

be 88.35 km and 1497 km, respectively. It is worth noting here that propagation distance estimated by PC2 is also a useful parameter for the monitoring of lightning in Southeast Asia. Figure 15 shows an example of subionospheric perturbations found in several transmitter signals in Japan. At the time indicated by red arrows, significant fluctuations are seen on the RIK-SAG and RIK-EBI data. It should be noted here that the SAG and EBI radio waves travel along the west side of Japan to arrive at the Rikubetsu receiver. On the other hand, the TOT and FUK radio waves travel along the east side of Japan. Therefore, the fact that perturbations were found only in the RIK-SAG and RIK-EBI signals suggests that the fluctuation source occurred on the west side. The most probable source is the Trimpi phenomenon that is a perturbation in the lower ionosphere due to the electron precipitation caused by interactions with lightning-induced Whistler waves.

5. Current Status and Future Prospective

Table 3 represents the development schedule of optical and VLF radio observation system. Most development processes described here was carried out in the period supported by the Grant for Next Generation Research Initiative under the JSPS Global COE program (E-04): In Search of Sustainable Humanosphere in Asia and Africa. So far, the manufacturing and fabrication processes were finished in 2007 and the observation systems were already installed or are ready for installations at each site.

During a period from 27 January to 2 February in 2008, an optical observation system was setup at Padang site and, on the night of 29 January 2008, test observation was carried out to check the full functionality of the system. As a result, no problem was found in the observation mode, image quality, and network connection. On the next day, by analyzing the obtained data with motion-capture software named “UFO capture”, 322 lightning events were found during 3.5-hour observation (see the results shown in Figures 10 and 11). After the installation, continuous observations have been carried out to date. Because a residential area is located in the camera-viewing direction, a masking structure was deployed to improve the lightning detection efficiency especially in the night time observation. So far, the system is set to record data during the period from 18 LT to 04 LT every night. Consequently, the amount of recorded data is about 3.4 GB per one night and, therefore, 5-month data can be stored on the 500 GB hard disk.

At Tainan site, a set of VLF observation system was installed on the roof of a building of National Cheng Kung University (NCKU) during 27-30 December 2007. In order to carry out test observations, a monopole, a dipole, and two loop antennas were fixed to the wall of the building. As a result of 11-months operation, it was found that the noise level was basically quite high and the detection efficiency of the system was too low for the current purpose. Therefore, a few potential sites in suburbs of Tainan city were surveyed from May to September 2008. Consequently, a building of the Cingcao elementary school located at 30 km away from NCKU was found to be suitable for VLF radio observations. In November 2008, the VLF system was reinstalled at the new site and

Table 3. A schedule of VLF observation network system. It is expected that the installations are finished at all sites by the end of 2008 FY or early 2009 FY.

Year	2007		2008												2009		
Month	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Preparation	Fabrication	⟶		Saraburi ↔			Saraburi ↔				Pontianak ↔			Saraburi		Pontianak	
Installation		Tainan ↔	Padang ↔												↔		↔
Maintenance											Padang ↔		Tainan ↔				

continuous operation was started.

At Saraburi (Thailand) and Pontianak (Indonesia) sites, preliminary site surveys were already carried out and some paper works are ongoing to prepare the installation of observation system. In February and May 2008, noise levels were surveyed at Saraburi site using a dipole antenna, an amplifier, and a handy receiver system. The obtained dynamic spectrum showed two transmitter radio waves at 18.1/18.2 and 19.8 kHz probably radiated from India/Russia and Australia, respectively. The signal-to-noise (S/N) ratio was 10-20 dB and the background noise level was better than 5 mV p-p, which suggests that the noise condition was sufficiently good for the monitoring of lightning and ionosphere. Since the Saraburi site is an area of Chulalongkorn University that would be used to construct a new campus, the area is not currently equipped with any necessary infrastructures. The setup processes of power lines, an air-conditioned container, and the internet accesses are now carried out to install the observation system and start operations in early 2009.

In September 2008, a noise level survey was carried out at Pontianak site, which is one of the LAPAN (LEMBAGA PENERBANGAN DAN ANTARIKSA NASIONAL) observatories. The site is equipped with full infrastructures (power line, building, internet access) and some scientific instruments such as an ionosonde, a wind profiler (WPR), and other meteorological observation systems. Since the ionosonde and WPR would radiate strong electromagnetic waves, severe noise level had been expected. Actually, the measured background noise level was quite high at a location 30-40 m away from both instruments. However, the noise level was found to be negligible by positioning the VLF sensors more than 100 m away. The obtained dynamic spectrum showed four transmitter radio waves at 18.1/18.2, 19.8, 22.2, and 25.0 kHz probably coming from India/Russia, Australia, Japan, and Russia, respectively. The S/N ratio was 10-30 dB and the background noise amplitude was better than 5 mV p-p, which is sufficiently quiet for our purpose.

6. Summary

In order to clarify the coupling process between lightning and their related phenomena, optical and radio observation network system is now under development in Southeast Asia. This network consists of an optical observation site in Padang and three VLF radio observation sites in Tainan, Saraburi, and Pontianak. At Padang site, a small low-light CCD camera was installed to observe the optical emission of lightning flash. On the other hand, a monopole, a dipole, and a set of orthogonal loop antennas were installed at the other three sites to detect electromagnetic waves in the frequency range of 0.1-40 kHz. The obtained data are used to monitor lightning in Southeast Asia and understand severe storms which cause significant damages on the human activity. As of December 2008, preliminary surveys at all the observation sites have been finished and, at Padang and Tainan sites, continuous operations have been started. So far, the full operation of lightning observation network system is planned to be started by the end of 2008 FY or early 2009 FY.

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