Horizontal difference between sprite-producing positive cloud-to-ground lightning and sprites during winter thunderstorm in Japan

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A number of papers have reported that a horizontal location difference between the sprite optically observed and the sprite-producing positive cloud-to-ground (+CG) lightning electromagnetically estimated often extended approximately 50 km. In order to elucidate the cause of the difference, we precisely measure the horizontal difference between sprites optically observed at three or four ground-based stations and the sprite-producing +CG lightning electromagnetically identified by several data sources, which might be expected to provide more accurate horizontal location. During two winter periods of 2012-2013 and 2015-2016 in Japan, seven events of sprites simultaneously observed at more than three optical stations in Japan were obtained. All events of sprites occurred within 5 - 10 km (7 ±3 km in average) horizontal distance from the largest luminescence of +CG lightning where the upper edge of +CG lightning return stroke was assumed. In the six of seven events and one, the horizontal distances between the center of sprites and the sprite-producing +CG lightning showed 14 - 22 and 7 km, respectively. In addition, column and carrot shapes of sprites could not be categorized by such horizontal difference.

Keywords: Sprite, Winter Lightning, Thunderstorm

Multi-point radiation measurements for gamma-rays from accelerated electrons in winter thunderstorm

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Recent on-ground observations have revealed that winter thunderstorm along the Japan sea radiates gamma-rays with energy extending up to 10 MeV (Torii et al., 2002, Tsuchiya & Enoto et al., 2007). Inside the thunderstorm, electrons are thought to be accelerated to relativistic energy by strong electric field, and to radiate bremsstrahlung gamma-rays. Currently, since the number of observation sites is limited, it has been difficult to trace time- and space-dependent changes of gamma-ray spectra. In order to resolve the electron acceleration mechanism inside thunderstorms (e.g., generation, growth, and disappearance of the relativistic electron acceleration region), we started to construct a new multi-point mapping system of the gamma-ray radiation, which can trace a path of the radiation and can detect a change of gamma-ray intensity and spectral change. In 2016-FY, we have developed a small, inexpensive FPGA/ADC board and a front-end electronics board to be coupled with BGO scintillators and PMT photo-diodes (see also Wada et al., JpGU session at the M-IS 18). We installed these new small radiation detectors on roofs of several high school and universities in Kanazawa prefecture, which area is famous for energetic winder thunderstorms. Our acquisition system has been collecting energy and arrival time (with GPS time tag) of individual photons, with environmental information (e.g., temperature, pressure). On 2016 December 8 and 9, we detected the gamma-ray radiation from winter thunderstorms at Kanazawa and Komatsu cities. We will report current status of our project and future prospects on understanding of the micro physics in the thunderstorms.

Keywords: winder thunderstorm, gamma-ray, electric field, electron acceleration

Intensity and frequency of electrified dust storms in the Middle East

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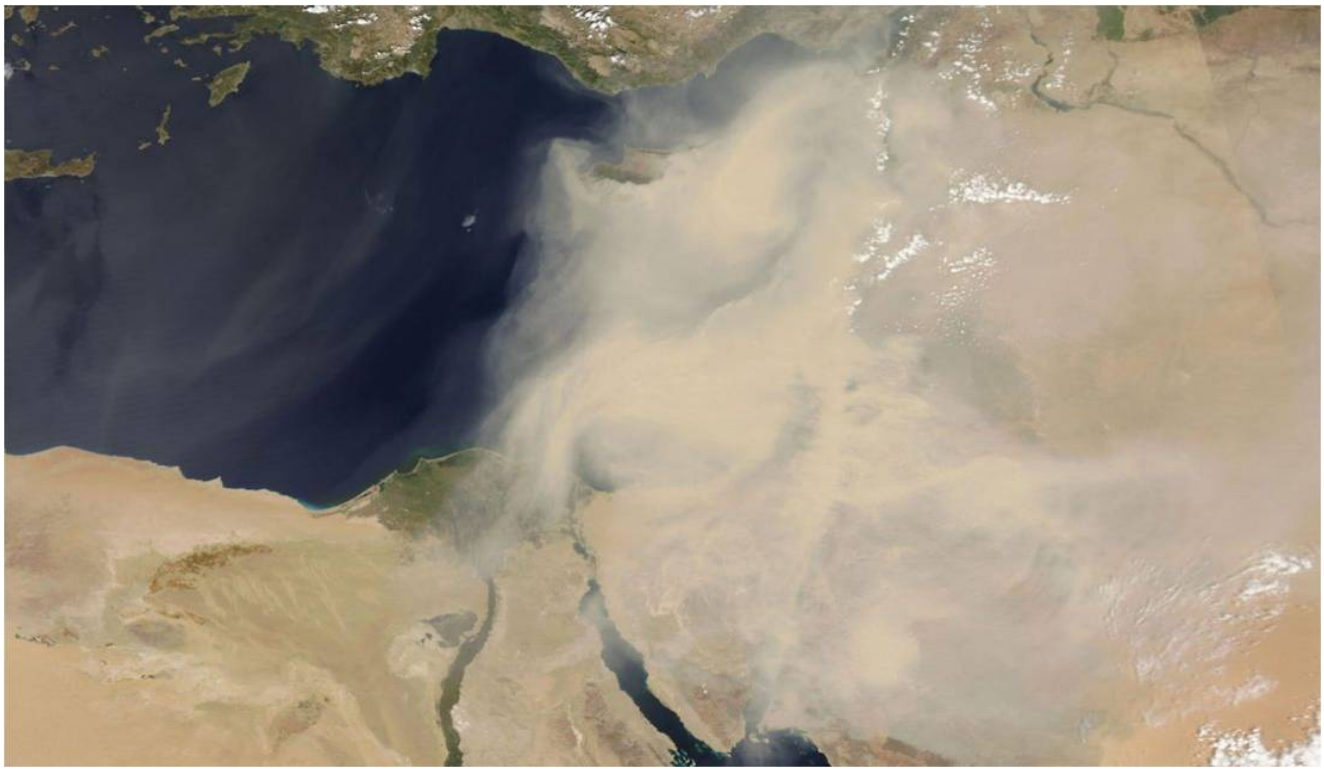
Dust storms in the Middle East are a common natural phenomenon and have become more frequent in recent years, due to the observed warming and drying trends attributed to regional climate change. Such dust storms are often accompanied by large electrical charging, most likely due to saltation and triboelectric processes. We present atmospheric electrical measurements conducted at the Wise Observatory (WO) in Mizpe-Ramon (30^{0}35’ N, 34^{0}45’ E, 850 MSL) and on Mt. Hermon (33°18’ N 35° 47’ E, 2200 MSL) in Israel. Atmospheric electrical measurements during several strong dust storms that occurred in the Middle East in 2015-2016 showed that when dust was being transported above the instruments, very large fluctuations in the electric field (Ez) and the current density (Jz) occurred. Values > 6 kV/m and peak current density of 12pA/m^{2} were observed, persisting for hours during peak aerosol concentrations. The electric field and current density variability and amplitude measured in all events deviate significantly from the mean fair-weather values at both sites. There are also notable differences in the polarity and magnitude of the observed electrical parameters between the dust storms, which are attributed to wind speed, dust episode duration and compositional differences of the soil in the source regions. These differences will be discussed and compared to dust storms in other regions.

Keywords: Electric Field, Dust Electrification, Regional Climate Change



Response of atmospheric electric fields to cloud parameters using a field mill and 95-GHz cloud radar FALCON-I

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It is known that lightning and precipitations of rain droplets generated from thunderclouds are the generator of global atmospheric electric circuit. In the fair weather, the atmospheric electric fields (AEF) are downward (positive), while they are upward (negative) during lightning and precipitations. However, the correlations between the AEF, and the cloud parameters such as cloud cover, weather phenomenon, have been not yet revealed quantitatively. In this study, we investigate the correlations between the AEF and the cloud parameters, weather phenomenon such like lightning and snow using a field mill, the 95 GHz-FALCON (FMCW Radar for Cloud Observations)-I and all-sky camera observations.
In this study, we installed a Boltek field mill on the roof of Engineering Research Building-2 in Chiba University, Japan, (Geographic coordinate: 35.63 degree N, 140.10 degree E, the sea level: 55 m) on the first June, 2016 to observe the AEF. The sampling time of the AEF is 0.5 s and the voltage range is ±20 kV/m. On the other hand, the FALCON-I has been originally developed by our group, and has observed the cloud parameters throughout 24 hours every day. The vertical cloud profiles and the Doppler velocity of cloud particles can be derived by the FALCON-I with high spatial resolutions (48.8 m). In addition, the images of the clouds and precipitations are recorded with 30-s sampling by an all-sky camera using a CCD camera on the same roof during 05:00-22:00 LT every day. The distance between the field mill and the all-sky camera is 3.75 m, while the distance between the field mill and the FALCON-I is 76 m.
We developed the automatic procedure to estimate the cloud cover from cloud optical images using the RGB color values. We estimated the correlation between the AEF and the cloud cover during 05:00 LT – 22:00 LT, June - November, 2016. The AEF decreased with increasing the cloud cover. The standard deviation of AEF was small when the cloud cover increased.
During 08:30 UT –10:30 UT, on 4 July, 2016, we found two kinds of variations in the AEF. One was slow variation due to the movement of thunderclouds, and the other was rapid variation associated with lightning discharges. As for the movement of thunderclouds, the AEF increased when the upper cloud was located over the field mill, which was opposite direction of the previous studies (Boltek Corporation, 2015). This change might be due to the positive charges in the upper cloud more than 14 km altitudes. As for the rapid variations of the AEF, 12 peaks of the AEF coincided with the occurrence of the lightning located within 37 km from the field mill.
On 23-24 November, 2016, we found the variation of the AEF due to snowfall. The AEF oscillated largely during snowfall. The period of the oscillation was about 72 minutes 49 seconds by FFT.
In this session, we will discuss the cause of the variations in the AEF during lightning and snowing.

Keywords: Atmospheric electric fields , Field mill

Recent results from the Japanese total lightning network

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In recent years, the relationship between the lightning activity and extreme weather phenomenon has gotten a lot of attention. In this paper, we will demonstrate the recent results from Japanese total lightning detection network (JTLN) in relation with extreme weather events in Japan. We will show that the flash rate of total lightning tends to increase about 20 minutes before the onset of the extreme weather event.

Keywords: lightning, wind gust, total lightning, extreme weather

Research of derivation of lightning electrical characteristics using by lightning irradiance observed from ISS

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In this paper, we compare lightning irradiance / lightning integral irradiance observed from GLIMS (Global Lightning and sprIte MeasurementS on JEM-EF) mission onboard ISS with current moment / lightning charge moment derived by ground based observation of ELF magnetic field observation, and verified the accuracy of the derived values. As a result, we got the high correlation (correlation coefficient > 0.76) between two values. We think that lightning charge moment, which is the energy of lightning discharge, estimated by only optical observation from space.

Keywords: International Space Station, GLIMS, ELF, Lightning charge moment

SATREPS project for development of extreme weather monitoring and alert system in the Philippines

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Thunderstorm causes torrential rainfall and is the energy source of typhoon. In these decades it has been revealed that lightning discharge is a very good proxy of thunderstorm activity. However, no operational and sustainable observation system that can provide information of charge moment changes for most of lightning strokes has been established. On the other hand, 50-kg micro-satellite is now one of the operational tool for remote-sensing, which could be fabricated by developing countries. SATREPS project titled “Project for development of extreme weather monitoring and alert system in the Philippines” will be carried out in the fiscal years of 2017-2021 under bilateral cooperation between Japan and Philippines supported by JST and JICA. In this project, we make use of two new technologies, that is, the lightning activity estimated by the ground-based lightning networks with ~10 sites for VLF radio wave measurement in nation-wide of Philippines and with ~50 sites for electrostatic field measurement in Metro Manila, and the 3 dimensional capturing of thunderstorms by the on-demand operation of remote-sensing by 50-kg micro-satellites. We will establish a new way to obtain very detail semi-real time information of thunderstorm and typhoon activities that cannot be achieved only with existing observation methods. Based on these new techniques together with advanced radar system and drop/radio sondes, we will try to construct the cutting-edge observation system to monitor the development of thunderstorm and typhoon, which may greatly contribute to the prediction of disasters and the public alerting system.

Keywords: lightning, micro-satellite, thunderstorm

Heavy rainfall observation in Metro Manila, Philippines for understanding the relation of lightning activity and tropical cyclone

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The Philippines is an archipelago country which is located in the western side of tropical western Pacific. Nearly 20 tropical cyclones in a year approach Philippine area. There are distinct summer monsoon in the western side of the country including Metro Manila. The project of Science and Technology Research Partnership for Sustainable Development (SATREPS) starts from April to develop a methodology on short term forecast of extreme weather (torrential rainfall and lightning) and typhoon intensities in Metro Manila cooperating with Researchers of Advances Science and Technology Institute (ASTI) in the Philippines. Summer monsoon rainfall in the western side of the Philippines including Metro Manila is intensified when the tropical cyclone passes over the Philippine Sea. Even when tropical cyclone does not land in the Philippines, moist southwesterly wind prevails in the west of Philippines associated with the circulation of tropical cyclone. We will deploy lightning detecting network in the Philippines to understand the relation of heavy rainfall and lightning activity. Several kinds of field observations of upper-air observations and dropsonde observations are planning to capture the atmospheric structure of thunderstorm clouds and tropical cyclones in the Philippines.

Keywords: lightning, tropical cyclone, Philippines

Changes in extreme rainfall in the Philippines for the 100-year period (1911-2010)

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Extreme rainfall values were examined to detect long-term changes in the Philippines and to investigate whether such changes are associated with the rising near-surface global mean temperature and the El Niño–Southern Oscillation (ENSO) for the 100-year period (1911-2010). The generalized extreme value distribution was formulated to its stationary and non-stationary forms, and then was fitted by the maximum likelihood method to the series of daily rainfall annual maxima (RX1day) at 23 meteorological stations in the Philippines. Subsequently, statistically significant changes in extreme rainfall in the country were detected. Such changes were further linked to the near-surface global mean temperature and ENSO. Specifically, the study has revealed a country-averaged increase in the median intensity of extreme rainfall associated with the rise in the near-surface global mean temperature. Furthermore, a seasonal influence of ENSO on extreme rainfall in the Philippines has been shown. In particular, the stations located in the northwest section of the country, where 75–100% of the RX1day occurred in the summer monsoon season (July–September) during the entire period of 1911–2010, showed an average increase in the median intensity of extreme rainfall associated with the ENSO index. These findings imply a potential intensification and increase in the occurrence of extreme rainfall into the future as the global mean temperature continues to rise, and such trends should be considered in adaptation strategies to minimize the disasters caused by extreme rainfall events in the Philippines. In order to minimize these disasters appropriate early detection system of heavy rainfall events are urgently needed in this country.

Keywords: climate change, extreme rainfall, global warming, generalized extreme value distribution

Doppler radar observations on the structure and intensity of tropical cyclones in the Ryukyus and the Philippines

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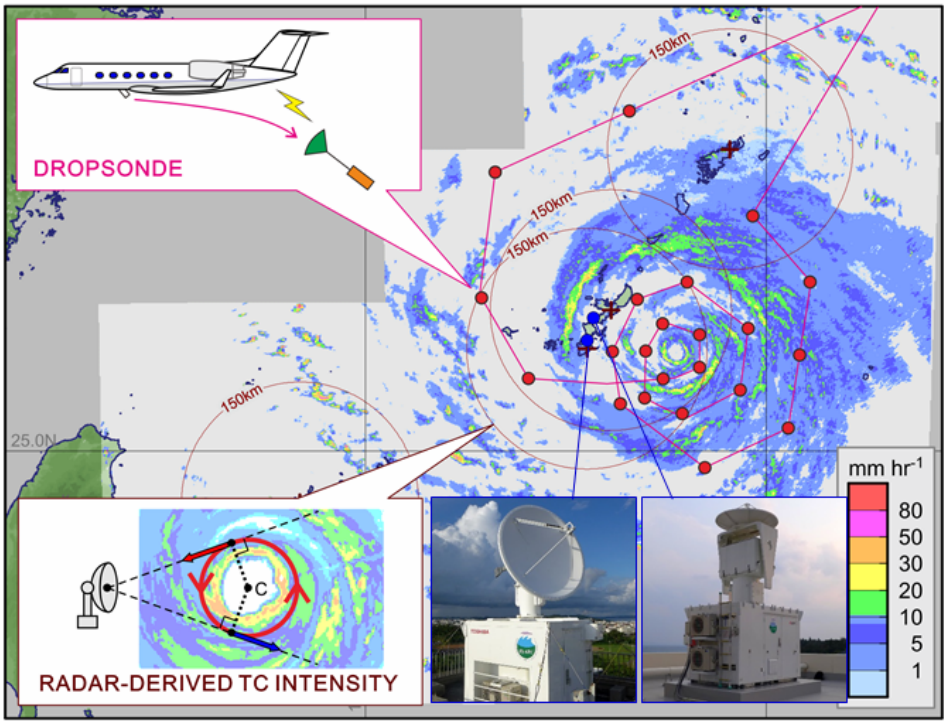
The western North Pacific is the basin with the largest number of tropical cyclones on the planet. Previous studies pointed out the frequent occurrence of rapid intensification and the increasing number of these cases in recent years. The accurate estimation of tropical cyclone intensity is essential for both disaster prevention in the coastal regions and further understanding of physical mechanisms governing intensification. We investigate the relationship between the structure and intensity of tropical cyclones using Doppler weather radars operated in the Ryukyu Islands of Japan and those along the Pacific coast of the Philippines. Analyses were made for several intense typhoons including Haiyan (2013), Goni (2015), and Chaba (2016). In addition, we found the rapid development and subsequent weakening of Kompasu (2010), which is not on the best track records. In these analyses, we focused on the slope angle of the eyewall and its relationship to flow structure and intensity. The relationship between the eyewall skewness and lightning activity from a viewpoint of cloud microphysics is also within the range of our interest. In this presentation, an overview of dropsonde observation of typhoons starting this year using a Gulfstream-II jet airplane will also be introduced.

Keywords: tropical cyclone, tropical meteorology, Doppler radar

Field Experiment of TC Intensity and Structure in Okinawa

(by Nagoya University, University of the Ryukyus, and MRI-JMA)



Lightning and Radar Observation for Severe Weather Mitigation

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This presentation reviews recent progress in lightning and radar observation for severe thunderstorm, and focus on the relationship between lightning and thunderstorm characteristics. The relationship between lightning flash rate and storm height has been investigated to predict the lightning production from cloud observation. Physical basis to support the relationship comes from the theory that the flash rate is strongly affected by the strength of the charge separation and the geometry of the charge distribution, in which vertical air motion plays a fundamental role. Hence, the flash rate is expected to depend on the intensity of the vertical air motion that is closely related to the storm height. As a practical matter, a case study shows that the flash rate increases as the updraft intensifies and the storm height develops[Goodman et al., 1988]. However, both theoretically and experimentally established correlation between storm height and flash rate is rare. In this study, the relationship between cloud height and lightning flash rate is examined on a global basis using data from the Tropical Rainfall Measuring Mission (TRMM) satellite.

Infrasound multi-site observation of thunders: a preparation for SATREPS

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Infrasound is considered as one of the remote-sensing method of lightning/thunders. Small but impulsive pressure changes caused by rapid expansion of heated plasma/neutral particles along the path of lightning strikes can make shock waves, then it can be detected by infrasound sensors with higher sensitivity range of 10 mPa or less on ground. In 2016, we installed infrasound sensors at three sites with a separation about 15 km in Kochi prefecture and a lightning/thunder event was successfully detected simultaneously at the every three sites on Dec. 13, 2016. Fortunately, the detected event was confirmed as lightning flash by a high sensitivity video camera operated mainly for meteor orbit detection. Forward-scattering radio meteor observation at two sites also detected impulsive lightning signal at the same time. From the comprehensive observation, exact location of the lightning strike was calculated in detail for this example with an error range within 300 m or less. By using the speed of sound as a precise remote-sensing ruler, the infrasound multi-site observation could reveal the lightning activities as close as 100 m scale when the infrasound sensors can be installed with a mesh of 10 km scale or denser. In this talk, we will introduce a possibility of infrasonic remote-sensing for the coming era of internet of thing (IoT) even in the field of geophysical and disaster-prevention studies in the world.

Keywords: Infrasound, Remote-sensing

Study on electrical activity of small convective clouds by using a vertically scanning X-band marine radar

*Yasushi Fujiyoshi

The author is interested in electrical activity of small convective clouds, especially winter snow clouds. Multi-paprameter Doppler radars are quite useful tool to classify hydrometeors type. However, their relatively low temporal and spatical resolutionThe author is interested in electrical activity of small convective clouds, especially winter snow clouds. Multi-parameter Doppler radars are quite useful tool to classify hydrometeor type. However, their relatively low temporal and spatial resolution may limit the research topics to such larger scale of storms as a severe hailstorm and organized convective systems. The lifetimes of small convective clouds (less than several km both in height and width) are generally less than 30 minutes. Their radar echo structures change rapidly associated with formation, growth and distribution of hydrometeors within clouds. Therefore, we studied the relationship between the electrical activity and temporal change in radar echo structure of convective clouds by using a conventional X-band marine radar. Its temporal and spatial resolutions are 2 seconds and 12.5 m, respectively. We conducted simultaneous observation of a vertically scanning X-band marine radar and a field mill deployed on the roof of ILTS of Hokkaido University, Sapporo, from 2013 to 2017. The horizontal and vertical detection ranges of the marine radar are 4 km and 7 km, respectively. Since this radar scans very fast, lightning echoes were sometimes detected as reported by Ligda (1956).
It is well known that the lightning activity of winter snow storms in Hokuriku district, southeastern coastal area of the Japan Sea, is quite high. On the other hand, it is empirically known that the lightning activity of snow clouds in Hokkaido, northern Japan, is much weaker than that in Hokuriku district. The temperature at the radar echo top (20 dBZ) and the altitude of the -10 ℃ level are used as good indicators of lightning activity in winter convective clouds in Hokuriku district (Michimoto 1989). Michimoto (1993) also proposed several criteria to classify the lightning activity.
In this study, we applied the criteria proposed by Michimoto (1989, 1993) to winter snow clouds in Sapporo to study the reason of the low lightning activity in Hokkaido. We used the data observed by an X-band marine radar and a field mill deployed on the roof of ILTS of Hokkaido University during 2013-2017 winter seasons. It is found that almost all winter thunder clouds in Sapporo were found within the criteria (-10 ℃ level < 1.8 km and temperature at the radar echo top < -20 ℃), where snow clouds exhibited no lightning activity or only very weak lightning activity in Hokuriku district. Electric activity of snow clouds in Sapporo became high when radar echo top height exceeded -15 ℃ level. It is also found that multi-cell type of convective snow clouds with much radar echo amount above -15 ℃ level are electrically quite active.

Keywords: electrical activity, snow cloud, X-band marine radar

Short-term prediction of cumulonimbus basing on upstream low-level humidification as a radar data assimilation

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Thunderstorms are induced by well-developed cumulonimbus clouds in general. To predict the activities of lightning, evolution of cumulonimbus clouds should be predicted by some techniques. However, there are some difficulties in prediction of cumulonimbus clouds associated with chaotic properties due to strong non-linearity in cloud forming processes. Short-term prediction of rainfall is performed as the precipitation Nowcast by Japan Meteorological Agency. The nowcast is based on temporal extrapolation of radar observed rainfall distribution assuming the invariance. However, the evolutions of cumulonimbus clouds are accompanied by the significantly large variations. The accuracy of the nowcast remarkably decreases with forecast time. Numerical simulations of cloud-resolving atmospheric models have a capability to predict structures and evolutions of cumulonimbus clouds. However, some problems are included in the data assimilation processes which are calculated to create initial conditions of the simulations. The data assimilation uses computational costs and takes comparably long time until the prediction is produced. In addition, detailed structure within cumulonimbus clouds are not involved in the initial condition of simulations. Thus, the author proposes a new data assimilation scheme for short-term prediction of cumulonimbus clouds, which is named as upstream low-level humidification (ULH) method. In the data assimilation, meteorological radar data are used to detect signals of cumulonimbus clouds. Here, the radar reflectivity information are not used to modify variables of rain water content. Instead, the information is translated to that of initial structure of cumulonimbus cloud which produced observed intense rainfall. In practical, areas where rainfall intensity is larger than 10 mm/h are horizontally advected toward the upstream side with 10-40 minutes. The water vapor in the lower atmosphere below the level of free convection is forced to add to be saturated by the nudging technique. The nudging coefficient is 1 minute. The ULH plays a role in the approximated adjoint calculation for time integration of four-dimensional variational data assimilation. In the installed prediction system, 3-hour forecasts are performed every 10 minutes, because the predictions should be updated with a shorter time interval due to the strong chaotic properties.
This method was applied to a heavy rainfall event observed in the Kanto Plain on September 2, 2013. The heavy rainfall caused by a few cumulonimbus clouds was well predicted by the ULH method up to forecast time of 30 minutes. The upstream advection period of 20 minutes was appropriate for more accurate predictions. The predicted cumulonimbus cloud included a large vertical vorticity that seems to have been associated with the observed tornado. The ULH was also applied to a heavy rainfall event observed at Hiroshima, Japan on August 20, 2014. A line-shaped stationary rainband was observed as a cluster of cumulonimbus clouds. The observed rainband was also roughly predicted by the ULH method. However, there were some problems for ULH method. Unobserved intense rainfall are sometimes predicted. The schemes to remove such unrealistic cumulonimbus clouds are currently developed. The ULH method have a possibility to predict cumulonimbus clouds. The possibility would be extended to predictability of lightning.

Keywords: cumulonimbus, short-term prediction, cloud-resolving atmospheric model

Dispersive and Non-dispersive Components in the L-band InSAR Image Associated with Heavy Rain Episodes

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Interferometric synthetic aperture radar (InSAR) is known to be a powerful technique to detect surface displacements with unprecedented spatial resolution, and has been applied to numerous earthquakes, volcanic eruptions, glaciers and ice sheets. Meanwhile, the effects of microwave propagation through ionosphere and troposphere can generate non-negligible phase anomaly in InSAR data, which often keeps from detecting small-amplitude displacements. Correcting for the ionsphere and troposphere is therefore a long-standing issue for high-precision geodetic measurements. However, if ground displacements are negligible, InSAR image can tell us the details of the atmosphere.
Kinoshita and Furuya (2017, submitted) detected phase anomaly in ALOS/PALSAR InSAR data associated with heavy rain over Niigata area, Japan, and performed numerical weathr model simulation to reproduce the anomaly; ALOS/PALSAR is a satellite-based L-band SAR sensor launched by JAXA in 2006 and terminated in 2011. The phase anomaly could be largely reproduced, using the output data from the weather model. However, we should note that numerical weather model outputs can only account for the non-dispersive effect in the phase anomaly. In case of severe weather event, we may expect dispersive effect that could be caused by possible presence of free-electrons.
In contrast to GNSS system, SAR imaging is based on a single carrier frequency, and thus no operational ionospheric corrections have been performed in InSAR data analyses. Recently, Gomba et al (2016) detailed the processing strategy of split spectrum method (SSM) for InSAR, which splits the finite bandwidth of the range spectrum and virtually allows for dual-frequency measurements.
We apply the SSM to the heavy rain signals detected by L-band InSAR, and report the presence of phase anomaly in both dispersive and non-dispersive components. While the original phase anomaly turns out to be mostly due to the non-dispersive effect, we can recognize local anomalies in the dispersive component as well. We will discuss its geophysical implications, and may show other case studies.

Keywords: InSAR, Heavy rain, dispersive media, InSAR split spectrum method

Tracking mesoscale convective systems in a future warm climate

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The Amazon basin is the largest water shed in the world and its complex ecosystems play an important role on the regional and global climate system. Due to its warm and moist air, thunderstorms are widely frequent over the basin. A group of these individual thunderstorms can compose one larger, intense, persistent and complex thunderstorm, which is called mesoscale convective system (MCS). MCSs occur with high frequency in the Amazon basin. Besides severe weather, hail, strong winds and lightning, MCSs causes elevated rates of precipitation contributing to the local and global climatology. Even with the increases of the global temperature, other factors, such as deforestation and increased pasture area, are expected to influence the formation of rainfall systems over the Amazon basin. Thus, it is very important to investigate how will be the average occurrence and behavior of MCSs in the Amazon basin in climate change scenarios. We will investigate the behavior of the mesoscale meteorological systems in a future warm climate. Simulations with global domain models give few or none information about mesoscale systems. The present study is part of a larger investigation about the impact of the climate changes on the MCSs occurrence over the Amazon basin. To identify and track MCSs in future climate change projections, we used a modified version of the algorithm Forecast and Track the evolution of Cloud Clusters (ForTraCC) adapted to read precipitation files from the climate model in matrix format. As tracking MCSs requires precipitation data at high temporal and spatial resolution, we used outputs from a regional model with 10 km spatial resolution. The Regional Climate Model system version 4 (RegCM4) was nested in the Hadley Global Environmental Model 2 - Earth System (HadGEM2-ES). The following Representative Concentration Pathways (RCPs) is used: RCP4.5 and RCP8.5. The atmospheric component of the model works with horizontal resolution of 1.25˚ latitude ×1,875˚ longitude, 38 vertical levels and a time interval of 30 minutes; and the oceanic component is performed at a resolution of 1˚ latitude ×1˚ longitude (with increasing resolution near the equator), 40 vertical levels and 1 hour time interval.

Keywords: thunderstorms, mesoscale convective systems, climate change, Amazon basin

Cloud monitoring by the Philippines' first microsatellite DIWATA-1

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The Philippines' first microsatellite, DIWATA-1, is a 50-kg-class earth observation microsatellite, funded by Philippines' Department of Science and Technology (DOST), built by scientists and engineers from the Advanced Science and Technology Institute (ASTI) of the DOST, the University of the Philippines-Diliman (UPD), Tohoku University (TU) and Hokkaido University (HU). The main objective of DIWATA-1 is to assist in disaster monitoring and natural resource management, specifically in the areas of agriculture, fisheries and forest protection. For that purpose, DIWATA-1 has four different optical sensors for earth observation. By using these sensors, the earth observation data can be acquired with several ground sampling distances (GSDs) from 3m with a field of view (FOV) of 2 km x 1.5 km to 185 m with a FOV of 40 km x 20 km at an altitude of 400km.
To date, it is well known that the Philippines is one of the most vulnerable countries to natural disasters. In a year, on average, there are about 18-19 typhoons that enter the Philippine area of responsibility. Predicting areas that would experience heavy rainfall will give local governments more time to evacuate affected residents. However, there have been few attempts made to perform this early prediction using satellite remote sensing data. In this paper, we focus on cloud monitoring using images obtained by DIWATA-1. Cloud activity is highly correlated with intense rainfall or thunderstorms. New application using DIWATA-1's cloud monitoring could be one of the powerful approach to catch the precursor of such natural disasters.

Keywords: Microsatellite, Disaster monitoring

Methods for Development and Operation of Microsatellite Bus System and Ground Station in PHL-MICROSAT Project

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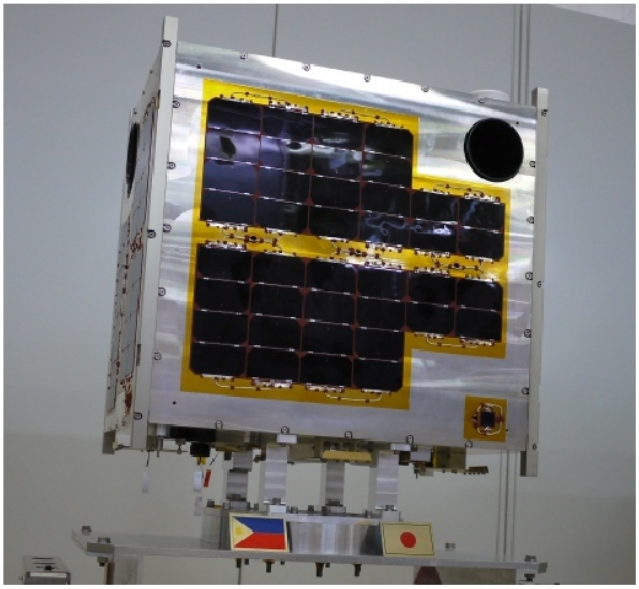
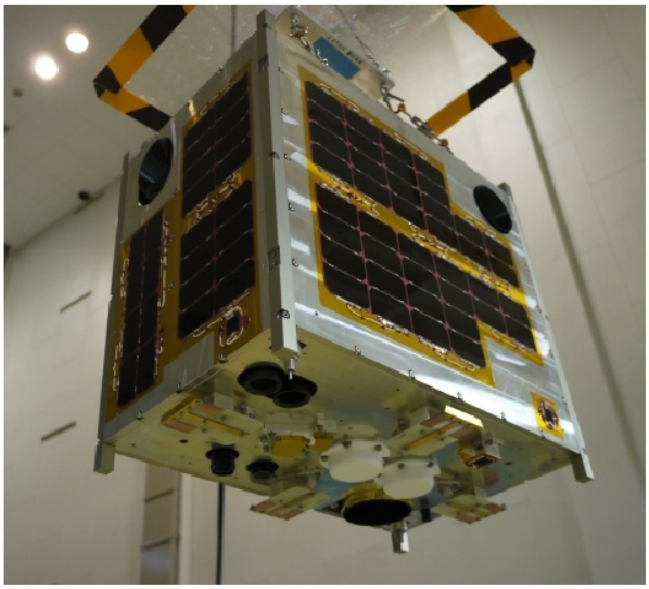
Since Tohoku University and Hokkaido University started the operation of microsatellite SPRITE-SAT(RISING) in 2009, 50-kg microsatellites dedicated for scientific earth observations are being developed and operated continuously. Inheriting the satellite bus system in RISING-2 which operation started in 2014 and RISESAT which is being developed, first Philippines' microsatellite DIWATA-1 could be completed and its operation started on April in 2016. This satellite is first satellite in the PHL-MICROSAT Project which is joint microsatellite development and operations by Philippines and Japan. In this presentation, development and operation experiences in satellite bus system for DIWATA-1 are described. This achievement can contribute to other new partners in Asian Micro-satellite Consortium (AMC) and technical requirements and performance about satellite and ground station development will be defined.

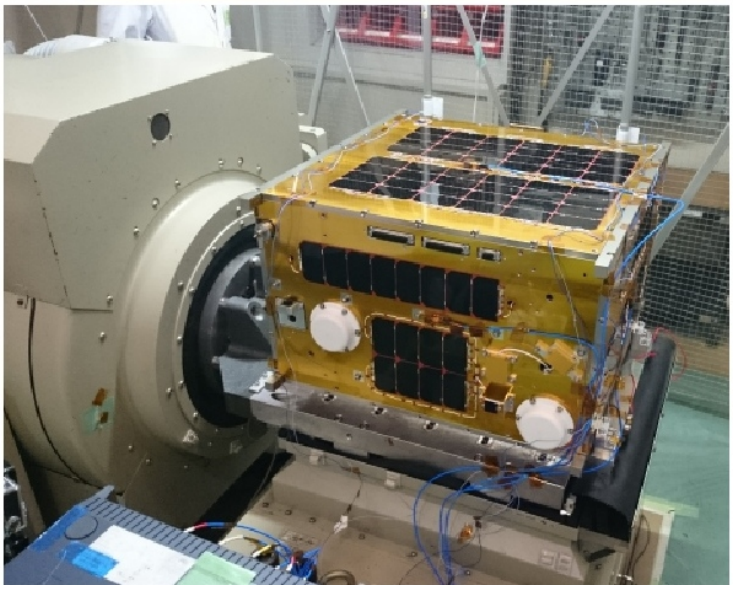
DIWATA-1 has 52.4-kg mass and the size is 55x35x55 cm. This was released into orbit by International Space Station (ISS) at 403-km height with 51.6-deg inclination. After about 2.5-year orbital lifetime, its mission will finish by re-entering to atmosphere. By using High Precision Telescope (HPT) with 3-m resolution and Spaceborne Multispectral Imager (SMI) with 61-m resolution, the satellite can observe the natural resources on ground, forest, and ocean in Philippines. The wavelength of SMI can be set with 1-nm step in the range of 430-1020 nm. By the attitude control function with target pointing mode, multi spectral images of same target place can be obtained in same observation opportunity.

Satellite bus system for DIWATA-1 was developed by six Filipino students under the supports by faculty members in Tohoku University. Preliminary design started on Nov. 2014, and the satellite could be delivered to launch organization in Jan. 2016, which total duration was only 14 months. To avoid the troubles in design, fabrication and environmental tests, deployment mechanism such as solar paddles was not adopted. Typical consuming power is 49.7 W in image capture mode and 56.9 W in data download mode although body-mount cells generate 38.6 Watts in average. To achieve the stable power management, the attitude control system is active only in Philippines and Japan, and it can safely return to power saving mode in other areas. Of course, the satellite has the ability to capture images also in other world areas. Next satellite DIWATA-2 will include a low-cost and high reliable solar deployable paddles and the observation ability will be upgraded more.

Satellite operation technology accumulated in Tohoku University was inherited to new satellite ground station which was constructed at Advanced Science And Technology Institute (DOST-ASTI) in Philippines. The satellite tracking antenna system is different from Tohoku University and its compatibility is not important. The automatic action of tracking antenna can be individual managed in Philippines and Japan. However, same transmitter, receiver, and satellite operation software were exported from Japan to Philippines to achieve the high-level compatibility in satellite operation methods. After the finish of initial operation from Japan, the methods to upload satellite operation commands and download observation images were transferred to Philippines' local operation team, then the satellite can be fully operated in Philippines now. In this PHL-MICROSAT project, quick construction of satellite operation system could be achieved as well as quick development of microsatellite. These experiences can contribute to next activities with new partnership in AMC.

Keywords: microsatellite, satellite bus system, satellite operation, DIWATA-1, Asian Micro-satellite Consortium



Effect of neutralization scheme on lighting simulation using a cloud-resolving model

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Introducing the lightning parameterization to the Cloud Resolving Storm Simulator (CReSS: Tsuboki and Sakakibara, 2002), we have simulated the location, number and types of lightning flashes. The lightning simulation includes three processes, (1) charge generation, (2) lightning propagation, and (3) charge neutralization. This study focuses on the charge neutralization scheme.
We The CReSS model adopted adopts riming electrification as the charge generation process (Takahashi, 1978). Lightning propagates along the maximum gradient of the electric potential (MacGorman et al, 2001). The net electric charge is neutralized along and around the lightning path. In this study, we used examined four neutralization schemes to evaluate the effect of neutralization scheme on lightning simulation. (1)The scheme I assumes that The the net electric charge for neutralization is distributed into each hydrometeor category according to its relative surface area (MacGorman et al, 2001). In this scheme, each category’ s charge is not necessarily decrease. (2) This The scheme II is more of the samesimilar to the scheme (1) I, but each category’ s charge is necessarily decreased. (3) This scheme is more of the same (1), butIn the scheme III, neutralization hydrometeor category is limited to same polarity as the net charge. (4) Ain the scheme IVVfter neutralization, the net electric charge is redistributed into each hydrometeor category according to its relative surface area after neutralization.
In this study, the lightning simulation calculates a case of the heavy rainfall system in the Kinki Area of Japan with a horizontal grid size of 2 km performed from 18:00 to 22:00 LST 23 August 2013. This result is compared with the observations. Compared The observation data is the Broadband Observation network for Lightning and Thunderstorm (BOLT: Yoshida et al, 2014). BOLT is a three-dimensional low-frequency lightning location system. It observes cloud-to-ground (CG) and intracloud (IC) flashes.
In the simulation of the presentthis case, thunderstorms are successfully simulated (Figure 1). This The result is compared with the observations about with regard to the temporal variation of lightning frequency. In the simulation, lightning occurred around a local maximum of rain rate, this result consistent with the observations. The temporal variation in numbers of simulated lightning is similar to observationed. However, simulated lightning number is larger than observations. Lightning number is dependent on lightning parameters and neutralization scheme. Therefore, optimizing the lightning parameter and understanding the neutralization scheme are essential for quantitative comparing comparison between the simulation and observation. Vertical cross sections of calculated lightning initiation is different from observations. In the observations, lightning initiation level is higher with higher lightning frequency is higher. However, simulated lightning height is almost constant, occurred around -10℃. This indicates that the Lightning lightning initiation height is without independent on dependence of neutralization schemes. We will investigate this result and improve lightning model in our future work.
Figure1. Locations of lightning flashes (a) observations (BOLT), (b) Scheme1Scheme I, (c)Scheme2Scheme II, (d)Scheme3Scheme III, (e)Scheme4 Scheme IVV in 19:30 LST 23 August 2013. Color indicates precipitation intensity observed JMA-radar and simulation experiments.

Keywords: lightning

Energetic radiation generated by winter thunderstorm and lightning observed in Uchinada, Japan

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We conducted energetic radiation measurement at Uchinada town, Kanazawa, during the winter thunderstorm. Active winter thunderstorm approaches the sea coast at Uchinada town and a number of cloud-to-ground winter lightning frequently occur. During our campagine observation on 2015-2016, we observed two short burst generated by lightnign stroke and five long burst attributed to electric field inside the thunderstorm . In this presentation, we introduce our results

Keywords: Energetic radiation, Winter Lightning, Thunderstorm

Latitudinal and Regional dependences of IC/CG ratio derived from JEM-GLIMS lightning observations

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The ratio between intracloud discharge (IC) and cloud-to-ground discharge (CG), denoted by Z, is important parameter for the studies on the severe weather prediction, the production of NO_X by lightning discharges, and the quantitative contribution of lightning to the global circuit. However, the difficulties of Z-value estimation in previous studies are originated in (1) the ground-based lightning data obtained at limited and specific areas, (2) difficulties in detecting IC discharges, and (3) difficulties in distinguishing the discharge types (IC or CG) in the previous space observation data. So, the latitudinal and regional dependence of Z-value are not resolved yet. In order to solve these problems, the Global Lightning and Sprite Measurements on Japanese Experiment Module (JEM-GLIMS) mission was launched in 2012, and it conducted nadir observations of lightning discharges using both optical instruments (Lightning and Sprite Imager: LSI and six-channel spectrophotometers: PH) and electromagnetic wave receivers. Thus, the final goal of this study is to estimate Z-value and to clarify its latitudinal and regional dependences and to evaluate the contribution of lightning to the global circuit as a generator. For this purpose, we have developed new methods to distinguish IC and CG using JEM-GLIMS optical data and ground-based lightning data. As a first step, we selected 707 lightning events detected by LSI and PH on board JEM-GLIMS in the period from Nov. 2012 to Aug. 2015. These lightning events were detected over both land and oceanic regions. Then, we compared the JEM-GLIMS data to the ground-based lightning data obtained by the Japanese Lightning Detection Network (JLDN), the National Lightning Detection Network (NLDN), and the World Wide Lightning Location Network (WWLLN) and identified the type of the lightning discharge detected by JEM-GLIMS, As a next step, we have calculated intensity ratios between blue and red PH channels, such as 337nm/762nm, 316nm/762nm, 392nm/762nm, 337nm/(599-900nm), 316nm/(599-900nm), and 392nm/(599-900nm) for each lightning event. It is found that 400 of 707 lightning events (56.6%) were identified to be CG discharges while 307 of 707 (43.4%) were IC discharges. It is also found that the PH intensity ratio of IC discharges is clearly higher than that of CG discharges. In the case of IC discharge, the ratio of 337nm/762nm, 316nm/762nm, 392nm/762nm, 337nm/(599-900nm), 316nm/(599-900nm), and 392nm/(599-900nm) are estimated to be 1.06, 0.21, 1.04, 0.16, 0.04, and 0.17, respectively, while those of CG discharges are 0.46, 0.16, 0.74, 0.03, 0.03, and 0.13, respectively. As the difference of the 337nm/762nm and 337nm/(599-900nm) ratio in IC case and in CG case is relatively large, these two ratios are the useful proxy to classify the discharge types for other 7650 lightning events detected by JEM-GLIMS. At the presentation, we will also show detailed results derived from the analyses of LSI data and ground-based ELF observation data.

Readiness in DOST-ASTI for SATREPS project for development of extreme weather monitoring and alert system in the Philippines

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Advanced Science and Technology Institute (ASTI) in Department of Science and Technology, Philippines (DOST) is the representative of Philippines side in SATREPS project “Development of extreme weather monitoring and alert system in the Philippines”. In this project we will construct lightning detection networks in Philippines with ~10 sites in nation-wide and ~50 sites in Metro Manila and operate micro-satellites in order to make stereo imaging of thunderstorm. ASTI has experiences to install water level sensors and automated rain gauges at more than 1000 sites in Philippines. Also ASTI together with University of Philippines, Diliman (UPD) has been contributing to the first Philippine micro-satellite project in development of satellite itself in Japanese universities and in ground operation in Philippines. ASTI and UPD will play essential roles in the development of software to estimate present and future precipitations based on the lightning activities and 3-demensional structure of thunderstorm captured by Philippine satellite “DIWATA-1” and others, as well as in the installation of lightning sensors at 60 sites and satellite operation.

Keywords: lightning, micro-satellite, thunderstorm, typhoon

Remote Sensing Assessment of Typhoon-Induced Vegetation Damage over the Philippines

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Philippines is an archipelago composed of 7,107 islands, located in the Southeast Asia. It is one of the the 18 mega-biodiverse countries in the world, containing two-thirds of the earth's biodiversity and between 70 - 80% of the world's plant and animal species. It is a country rich in natural resources but at the same time, it is vulnerable to numerous natural hazards. According to a study conducted by the United Nations Office for Disaster Risk Reduction (UNISDR) and the Centre on the Epidemiology of Disasters (CRED), over the past two decades (from 1995-2015), the Philippines endured a total of 274 natural calamities, making it the fourth most disaster prone country in the world. The main reason for this is its location. The country is located in the pacific ring of fire which explains the presence of numerous volcanoes, faults and trenches in the country. Its location in the pacific has also a high exposure to tropical cyclones. From 1990-2006, it was estimated by the Climate Change Commission of the Philippines that of the PHP 12.43 billion or USD 248.7 million average annual cost of natural disasters to the agricultural sector, about 70% is from damages brought by typhoons.

Remote Sensing is a cost-effective tool in analyzing areas that are challenging to observe with field surveys. With the presence of numerous satellites equipped with high resolution and multi-spectral sensors, images of areas hit by natural calamities are easily obtained few days after the disaster struck. Comparison of the Normalized Difference Vegetation Index (NDVI) method obtained pre- and post-storm is commonly used by numerous researches in detecting damages after a storm's passing.

In this research we examine typhoon-induced damage to vegetation by utilizing NDVI and relating it to the typhoon's features: wind and rainfall, and to the characteristic of the area hit: elevation, aspect and land cover type. This research is in support of the goal of rapid post-typhoon assessment in the Philippines with the use of its microsatellite, Diwata. In the future, we want to use images taken by Diwata in post disaster assessment.

Two typhoons were analyzed, Typhoons Haiyan and Koppu. Both hit the Philippines and brought devastating damages to the country. The area analyzed are the provinces of Leyte and Nueva Ecija for Typhoon Haiyan and Koppu, respectively. The main difference between these two storms is that Typhoon Haiyan carried with it strong winds more than heavy rainfall while Typhoon Koppu, on the other hand, carried more heavy rain than strong winds. In both cases the NDVI significantly decreased after the typhoon hit with values of -0.12 +- 0.13 (mean +- standard deviation) and -0.14 +- 0.14 with paired t-test p values < 0.001 for Typhoons Haiyan and Koppu, respectively. Damage as a function of rainfall, aspect, land cover type and elevation were analyzed for each case. We also calculated the influence of each variable to the measured damage using Artificial Neural Network. We found that the elevation is the strongest influence, followed by aspect, rainfall and lastly land cover.

Keywords: Typhoon, damage asessment, Philippines, Landsat

An observational study on lightning activities over the coastal region of Sumatra, Indonesian maritime continent

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Indonesian maritime continent (IMC) is an archipelago of large and small islands with complex terrain surrounded by warmer sea water. Convection and lightning activities over the IMC is very active in the tropics and acts as a global heat source of large-scale atmospheric circulation. In this study, we investigate lightning activities over the IMC by using worldwide lightning location network (WWLLN) data and sounding and weather radar data of pre-YMC (Years of the Maritime Continent) campaign observation on and off western coast of Sumatra, IMC in November-December, 2015.

As described in previous studies, diurnal cycle of lightning with clear land-sea contrast is predominant over the IMC. Frequent lightnings are observed over the Sumatra in the afternoon/evening, whereas the night/early morning peaks are predominant in the off coastal region of southern Sumatra and Malacca straight. Intra-seasonal variations of lighting are also observed in relation to the phases of MJO (Madden-Julian Oscillation). The causes of the spatial and temporal lightning variability in the coastal heavy rainfall region will be discussed by using in situ observation data. In addition, we will introduce an ongoing lightning observation project in Philippine, one of the maritime continent.

Monitoring of lightning activity with the combination of radio observation in ELF-VLF band and electrostatic measurement.

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In the recent, heavy rain and lightning associated with thunderstorm become a representative of severe weather in urban region. Lightning observation has been focused on as an efficient tool to monitor thunderstorm activity.
Main objective of this study is to established methodology for early detection of thunderstorm formation with simple and low-cost system. To observe lightning activity, electromagnetic field radiated from lightning discharge in ELF (Extremely Low Frequency: less than 3 kHz) and VLF (Very Low Frequency: 3-30kHz) bands has been measured. ELF-VLF wave can propagates long distance (more than several hundreds kilometers). Receivers are installed about 100 km apart in the Kanto Plan, Japan to make detection sensitivity to be high.
In this presentation, initial results of the combination of radio observation in ELF-VLF band and electrostatic measurement are summarized. As an electrostatic measurement, flat-plate sensor called as slow antenna is newly developed and installed at Machida, Tokyo. Based on the comparison between electric field data and electrostatic one, detection sensitivity and discharge-type identification of radio observation in ELF-VLF bands is validated.

Keywords: lightning discharge, thunderstorm, ELF, VLF, electrostatic field

Characteristics of Downburst Occurrences Derived from Ground-based Lightning and Meteorological Observations

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A prediction of the downburst occurrence using the existing meteorological observation networks is very difficult because the typical spatial and temporal scale size of downbursts are ~1.8 km and a few minutes, respectively. Once a downburst occurs in a metropolis, various infrastructures suffer huge damage. For this reason, a prediction of the downburst occurrence based on other observation methods is desired. At the convection cell accompanied by a downburst, active lightning activities are confirmed in many cases. In addition to this, we expect that not only the lightning occurrence number but also the charge amount neutralized by lightning discharges may be related to the vertical convection intensities in thunderclouds. So, the purpose of this study is (1) to develop a new method to estimate charge amounts neutralized by lightning discharges, (2) to clarify the relation between lightning activities and downburst occurrences, and (3) to identify the characteristics of downburst occurrences that can be used for the prediction of the downburst occurrence. As a first step, we have analyzed ELF data obtained at Onagawa and Kuju stations and compared ELF waveforms with the lightning current waveforms measured by the Rogowski coil at Mt. Ogami, Niigata. It is found that the cross correlation coefficient between these two waveforms became 0.80, which implies that the dominant component of the observed ELF waves is not the radiative but induction magnetic fields. We further estimated an empirical equation to calculate the charge amounts neutralized by lightning discharges (Q) from the time-integrated ELF magnetic field amplitude (ΣB). Using this empirical equation, it is first possible to estimate charge amounts of any lightning discharges occurred within ~1000 km distance from the observation site. As a next step, we analyzed 8 downburst events occurred in 2015 in Japan using ELF data, JLDN (Japan Lightning Detection Network) data, meteorological (C-band radar, AMEDAS) data provided by JMA, and POTEKA data provided by Meisei Electric Co., Ltd. It is found that the occurrence number of −CG discharges and the lightning charge amounts reached their peak just before/after the occurrence of the downburst in many cases and that the temporal variation of the lightning charge amounts is comparable to that of rain volumes. Thus, we can deduce that these characteristics of lightning activities are the good proxy for the prediction of the downburst occurrence. At the presentation, we will show the relation between ELF waveforms and lightning current waveforms and the results of lightning and meteorological data analyses in the downburst events in detail.

Keywords: lightning, downburst, prediction

Deployment Plan of ELF Observation System in Asian Countries to Monitor Severe Weather Development

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Recent studies on the relation between lightning activity and severe weather activity revealed that lightning occurrence numbers and charge amounts neutralized by lightning discharges are the good proxy to predict the intensity development of severe weathers. We installed an ELF observation system at Onagawa station in 2001 and Kuju station in 2013 and are conducting continuous measurements of ELF waveforms excited by lightning discharges. Using the ELF data and lightning current waveform data obtained by the Rogowski coil, which is installed at Mt. Ogami in Niigata, we found that the shape of the lightning-exciting ELF waveform is comparable to that of lightning current waveform. As the distance between the ELF station and the Rogowski coil is about 300 km, observed ELF waveforms are mainly induction magnetic fields and become proportional to lightning current waveforms. By comparing time-integrated magnetic field amplitude (ΣB) to time-integrated current waveform amplitude, which becomes the charge amount neutralized by lightning discharges (Q), we obtained an empirical equation to estimate the neutralized charge amount of any lightning discharges. Then, we analyzed the relation between the lightning charge amount and temporal development of thundercloud activity using both ELF and meteorological C-band radar data. It is found that the temporal variation of neutralized charge amounts of lightning discharges occurred at active thunderclouds is proportional to that of rain volumes, and it is also found that downbursts occurred just after/before the variations of lightning charge amounts and −CG occurrence numbers reached their peak. These facts imply that the measurement of ELF waveforms is a good and cheap way to continuously monitor meteorological conditions in active thunderclouds. From April 2017, the project of Science and Technology Research Partnership for Sustainable Development (SATREPS) will start. In this project, methodologies on a short term forecast of severe weather and typhoon intensities will be developed. For this purpose, 60 automatic weather stations equipped with slow-antenna lightning sensors and VLF receivers will be installed in Philippines. We will also install the same type of the ELF observation system in this project and will conduct continuous measurements of ELF waveforms excited by lightning discharges and meteorological conditions in active thunderclouds occurred near Philippines and other Asian countries. At the presentation, we will show the basic specification of the ELF observation system and discuss the usefulness of ELF measurements for the short term forecast of severe weather and typhoon intensities more in detail.

Keywords: lightning discharges, ELF waves, severe weather, extreme weather

Detection of natural hazards with very low frequency acoustic wave, infrasound

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Very low frequency acoustic waves so-called infrasound are often observed accompanied with severe natural hazards. One of the most prominent events are detected after earthquakes. The infrasound is emitted by the ground/sea surface motion arising from the earthquake. The infrasound reaches at several hundred km altitude, then disturb ionospheric plasma through collision with neutral atmosphere. These disturbances are often detected in the data of GNSS total electron contents (TEC). Furthermore, TEC disturbance was also found over a huge thunderstorm. Since the infrasound propagates not only vertical direction but also horizontal direction, the ground-based infrasound sensors also detect tsunami signature after the large earthquake under the sea. Therefore, the infrasound from the huge thunderstorm showing TEC disturbance is possibly detectable. In fact, detection of concentrated heavy rain using the infrasound has been attempted and the results show the potential ability of the detection. In addition, it was found that the infrasound was emitted from snowslides. The observation suggests that the infrasound is also emitted from land slide. Therefore, the infrasound is useful tool to detect the land slide accompanying with the heavy rain. When array observations are arranged, the location of the event can be estimated using time delay of the signals. Therefore, the infrasound observation can contribute the nowcast system to detect the heavy rain. Since the sensors are easy to maintain and operate, they are easy to install in the developing countries. Philippines also has many earthquakes. The infrasound observation can also contribute to reduce tsunami disasters as well as thunderous.

Keywords: infrasound, very low frequency acoustic wave, heavy rain, detection of natural hazard, land slide, tsunami

Cloud Observation by 3D Modeling Based on Camera Images

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Current weather radars used for short-term precipitation forecast mostly detect rain/snow droplets, which prevents from fully observing rapidly growing cumulus clouds that could cause severe weather until rain/snowfall starts. Phased array radars and other new radars have gradually been enabling to detect clouds but building and operating such radars would be expensive. In order to develop inexpensive methods to observe clouds before precipitation starts, images of the clouds captured with visible light cameras could be used to locate and make measurements of clouds. Previous studies have succeeded in locating clouds by calibrating cameras using various objects and landmarks, such as topographic features, locations of an airplane, the sun and stars. However, for the practical monitoring of clouds, it is important to investigate the proper conditions when capturing images to observe the clouds without any external calibration.
In order to observe the clouds, 4 images of the same cloud will be captured simultaneously at different locations using digital cameras (Nikon D5500). The images will then be imported into the 3D modeling software PhotoScanPro to align the photos, build dense cloud, and build 3D mesh model with which the location and size of the cloud will be calculated by tagging GPS location data. Up to now (15 Feb 2017), several experiments have been conducted using a lump of cotton as an object visually similar to clouds. (a) 4 images were captured with different dihedral angle between cloud-camera planes to examine the viability to generate 3D models and the accuracy of the calculated distance and surface area. Also, (b) another 4 images were captured with different light source position to examine the influence on the resulting models.
The results of the experiments are as follows: (a) as the dihedral angle increased, we reached a specific point where the software could not produce 3D models due to insufficient number of points matched by the software among multiple images. Also, as the angle widened, the accuracy of the calculated distance between the object and cameras got fairly high, covering the decent area of the cotton surface. This suggests that the specific angle is ideal even in the real photo-capturing situation. (b) The resulting 3D models did not vary with different locations of the light, which suggests that the slight change in the brightness and contrast caused by different location of the sun does not greatly affect the 3D models.
The results demonstrate some aspects of the proper conditions when capturing images. For further investigation, we are planning to examine the accuracy of volume measurements using a piece of clay and we will keep on looking into other conditions that might affect the resulting 3D models and the accuracy of measurements. Another experiment is also planned to take actual photos of clouds and generate 3D models using them in order to evaluate the validity of the experiments. Finally, we will apply the above optimal conditions to the actual photo-capturing situation to acquire consecutive cloud images to construct 3D models and will make measurements, the accumulation of which helps determine criteria for the future forecast of precipitation and severe weather.

Keywords: Cloud Observation, Cumulus Cloud, 3D Models, Camera Images, Severe Weather Forecast

Demonstration for hyper-dense meteorological observation using low-cost wireless sensor network

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Recent climate changes can increase severe weather events, such as a heavy rainfall, thunderstorm, and a gusty wind. Techniques for monitoring and predicting those are very important to reduce the hazards in disaster-prone areas. To monitor the local severe weather of several km^2, however, remains a challenge. Moreover, most of the disaster-prone areas are located at developing countries. Thus, it is needed for a low-cost and hyper-dense meteorological monitoring system at a spatial resolution better than ~250m. Here, we have developed hyper-dense meteorological observation system (50-100m intervals) using low-cost wireless sensor network, demonstrating it for cross-country skiing course. Hyper-dense meteorological observation in the cross-country skiing can help us to select a suitable glide wax, which work as a reduction of the friction between skiing and snow surface. We must select the wax judged from meteorological conditions, such as temperature, humidity, illuminance, etc. in the whole course. We have measured those using the sensor sets of temperature, humidity, and illuminance at ~30 observation points placed on the interval of 50-100m on the actual cross-country skiing course (Hokkaido). Observed meteorological data were recorded by PC through the wireless sensor network (XBee). We have succeeded in multi-point meteorological observation for the actual of cross-country skiing course. This observation system can not only use in developing country to monitor the local severe weather events, but also provide a basic data to forecast those.

Keywords: Wireless sensor network, Hyper-dense meteorological observation, Cross-country skiing

