

国際宇宙ステーションからの雷放電とスプライトの観測 (GLIMS) Global Lightning and Sprite Measurements (GLIMS) from ISS

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The Global Lightning and sprItE MeasurementS (GLIMS) on the International Space Station (ISS) is a mission to detect and locate optical transient luminous events (TLEs) and its associated lightning simultaneously from the non-sun synchronous orbit, and is scheduled to be launch from Japan in January, 2012 as part of the multi-mission consolidated equipment on Japanese Exposure Module (JEM). Our mission goals are (1) to detect and locate lightning and sprite within storm scale resolution over a large region of the Earth's surface along the orbital track of the ISS without any bias, (2) to clarify the generation mechanism of sprite, and (3) to identify the occurrence conditions of TLEs. To achieve these goals, two CMOS cameras, six Photometers, VLF receiver, and VHF interferometer with two antennas, are installed at the bottom of the module to observe the TLEs as well as causative lightning discharges at nadir direction during day and night time. Though the luminous events so-called sprite, elves and jets have been investigated by numerous researchers all over the world based mainly on the ground observations, some important problems have not been fully understood yet such as generation mechanisms of columniform fine structure and horizontal offset of some sprites from the parent lightning discharges. In the JEM-GLIMS mission, observations from our synchronized sensors are going to shed light on above-mentioned unsolved problems regarding TLEs as well as causative lightning discharges.

The GLIMS was launched to the ISS on July 2012 and started its initial observation from November 2012 after the initial testing successfully. In this presentation, the mission overview and some intial results are briefly and firstly reported before some of the co-authors presents the interesting results more explicitly.

キーワード: 雷放電, 高高度発光現象, 国際宇宙ステーション

Keywords: Lightning, TLE, ISS

JEM-GLIMS による光学観測の初期結果報告 Initial Results Derived From JEM-GLIMS Optical Observations

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JEM-GLIMS is a space mission to carry out the nadir observations of lightning and TLEs from International Space Station (ISS). The final goal of this mission is to identify the spatial and temporal evolutions of lightning and TLEs and to clarify the occurrence conditions of TLEs. JEM-GLIMS consists of four science instruments; (1) Lightning and Sprite Imager (LSI), (2) six-color spectrophotometer (PH), (3) VLF receiver (VLFR), and (4) VHF interferometer (VITF). LSI will acquire lightning and sprite images with a frame rate of 29 fps, and PH will measure absolute intensities of lightning and sprite emissions with a sampling frequency of 20 kHz at the different wavelength of 150-280, 316, 337, 392, 762, and 600-900 nm, respectively. VLFR will measure electromagnetic waves in the frequency range of 1-40 kHz, while VITF will measure VHF pulses in the frequency range of 70-100 MHz. From these science instruments, it is possible to identify the optical occurrence characteristics of lightning and TLEs and the electric characteristics of the TLE-inducing lightning discharges. JEM-GIMS was successfully launched and transported to the ISS, and it was successfully installed at the Exposed Facility of the Japanese Experiment Module (JEM) on August 9. Finally, a continuous observation of lightning and TLEs by JEM-GLIMS was started from December 20, 2012. Up to the end of January 2013, JEM-GLIMS has triggered and recorded 350 transient optical events in total, where strong lightning signatures are confirmed in LSI and PH channels. For some of these events, transient signatures of N2 LBH are confirmed in the PH1 photometer, which strongly implies the occurrence of TLEs. At the presentation we will report more detailed initial results derived from JEM-GLIMS data.

キーワード: 雷放電, スプライト, グリムス・ミッション, 国際宇宙ステーション
Keywords: Lightning, Sprite, GLIMS mission, International Space Station

国際宇宙ステーションからのVHF帯電磁波を用いた雷観測 VHF observations on lightning discharges from the International Space Station

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We present the lightning observation missions from space using the electromagnetic waves.

In 2012, Global Lightning and sprIte MeaSUREMENTS (GLIMS) mission has been conducted on Exposed Facility of Japanese Experiment Module (JEM-EF) of the international space station (ISS) which is orbiting the earth at an altitude 400 km. The VHF broadband digital interferometer (VITF) attached on JEM-EF is designed to estimate the direction of arrival of electromagnetic waves. The VITF has the bandwidth from 70 MHz to 100 MHz. The VITF on GLIMS is developed on the heritage of a VHF sensor on Mado-1 satellite. The VITF consists of two antennas, band-pass filters, amplifiers, and 2-channel-AD-converter. The electromagnetic radiations from lightning discharges received by the antennas are digitized by the AD converter synchronizing with another channel through the filters and the amplifiers. The band-pass filter and the amplifier of the VITF are exactly the same as the ones of the VHF sensor on Mado-1 satellite. The basic specification and most of devices in the AD converter of VITF are proven by the one of VHF sensor on Mado-1 satellite.

We will introduce the outline of the mission and the VITF. The initial observational results with the VITF of the JEM- GLIMS mission will be presented. We discuss the results and the VHF wave propagation characteristics through the ionosphere.

キーワード: 雷放電, 電磁波, 電波観測

Keywords: lightning, electromagnetic waves, radio observation

JEM-GLIMS による雷・TLE の天底観測 : ISUAL リム観測との比較 Nadir observation of lightning and TLEs by JEM-GLIMS: Comparison with ISUAL limb observation

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The present study analyzes the optical data of lightning and TLEs obtained by JEM-GLIMS on the International Space Station. In contrast to former studies based on the ISUAL limb observation, JEM-GLIMS is pointed toward nadir and, thereby, provides an innovative way to clarify the horizontal structures of lightning and TLEs, which are one of the most crucial issues to improve our understanding of atmospheric discharge physics and electrodynamic coupling between the troposphere and the ionosphere. A difficult point, however, is that careful analyses are required to separate the optical emissions of lightning and TLEs which spatially overlap in the field-of-view in the case of nadir-looking geometry.

The main data analyzed here are those obtained by GLIMS dual-color imager (LSI) and six-color spectrophotometer (PH). One LSI channel is equipped with a 762-nm filter to selectively detect high-altitude TLE emissions by minimizing contamination from low-altitude lightning emissions by deep O₂ atmospheric absorption while the other LSI channel has a broadband red filter to equally measure both phenomena. PH detects time-resolved emission intensity at a sampling rate of 20 kHz with six channels measuring at 150-280, 337, 762, 600-900, 316 and 392 nm, respectively. These spatiotemporally- and spectrally-resolved optical data are analyzed in comparison with well-calibrated results obtained by the ISUAL limb observation of lightning and TLEs.

The goal of this study is to separately identify the signatures of lightning and TLEs from GLIMS data and precisely clarify their spectral and spatiotemporal characteristics.

キーワード: 雷, スプライト, 大気電気, GLIMS, ISS, 宇宙機

Keywords: lightning, sprites, atmospheric electricity, GLIMS, ISS, Spacecraft

Remote sensing of thunderstorms and TLEs by RISING-2 microsatellite Remote sensing of thunderstorms and TLEs by RISING-2 microsatellite

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Tohoku University and Hokkaido University developed a new 50 kg-class microsatellite RISING-2, which will be launched in sun-synchronous (12 LT) polar orbit at 628 km altitude as a piggyback of the ALOS-2 satellite with H-IIA rocket in 2013. This satellite inherits the development technique of RISING (SPRITE-SAT), which was designed for the observations of TLEs and launched on January 2009. In addition to the Lightning and Sprite CMOS Imagers (LSI) installed on RISING and JEM-GLIMS, RISING-2 carries a new optical instrument, High Precision Telescope (HPT), developed by Hokkaido University. HPT uses a Cassegrain telescope with 10-cm diameter and 1-m focal length and can observe the earth surface with 5-m GSD. HPT has four sensitive CCDs, and three of them are allocated to Red/Green/Blue bands to make color images. The other CCD is for multispectral observations in the near-infrared region (650-1050 nm) using a Liquid Crystal Tunable Filter (LCTF). LCTF can change the center wavelength to transmit the near-infrared light with the mean band width of 20 nm. By the three-axis attitude stabilization of RISING-2, HPT is able to observe the designated area or direction from the orbit. This allows flexible observations of thunderstorms and TLEs from space with high spatial resolution.

航空機からのハイスピードカメラ観測により明らかとなった スプライトストリーマの時間・空間進展機構 Spatial and Temporal Evolution of Sprite Streamers Derived from High-Speed Camera Data in Aircraft Observation Campaign

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The occurrence conditions of sprites streamers still remain to be an unsolved problem after the discovery of sprites. Though the detailed three-dimensional spatial structures and the temporal evolution of sprite streamers are the key parameters to clarify the occurrence conditions, these spatiotemporal characteristics are not clearly identified. In order to specify the detailed spatial and temporal evolution of sprite streamers, we have conducted the optical observation campaign using high-speed cameras from two jet aircrafts in summer US. In this campaign, we succeeded to capture sprite images for 28 events by the high-speed cameras with a sampling rate over 8,000 fps at each aircraft simultaneously. Using these image data, we have performed triangulation analysis to estimate the horizontal spatial distribution and vertical extent of sprite streamers. We have analyzed two types of columniform sprites; one is the columniform sprite with a preceding dense inhomogeneous halo, and the other is the columniform sprite with a preceding dim halo or without a halo. In the later case (dim halo plus columns), the following results are identified. (1) The longer the distance between sprite columns and the parent CG becomes, the higher the bottom altitude of columns becomes. (2) The longer the distance between sprite columns and the parent CG becomes, the slower the speed of downward streamer tips becomes. These results are first clear observational evident showing the horizontal spatial gradient of the quasi-electrostatic field produced by the parent CG discharge. At the presentation, we will show the electrical characteristics of the parent CG discharges derived from CMC waveforms and will discuss the possible mechanisms determining such spatial dependences.

スプライト構造化に対する力学モデルアプローチ A dynamical model approach to structuring of sprites

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Our recent theoretical studies for structuring of sprites on the basis of quasi-electrostatics and multi-body dynamical model are presented in this talk. The phase transition theory between halo and streamer states has been proposed, and a similar transition could be found in a variety of macroscopic structures of sprites as column and carrot shapes. We construct a multi-body dynamical model that treats the interaction, acceleration, and splitting of streamers in a lightning-induced quasi-electrostatic field. We investigate sensitivity of streamer development to the lightning (measurable) parameters and provide implications for the condition of the phase transition of sprites.

キーワード: スプライト, 力学モデル, 相転移

Keywords: sprite, dynamical model, phase transition

Characteristics of Transient Luminous Events in Eastern Mediterranean Thunderstorms: Results from a 7-Year Survey

Characteristics of Transient Luminous Events in Eastern Mediterranean Thunderstorms: Results from a 7-Year Survey

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Lightning activity in the Eastern Mediterranean and the vicinity of Israel is prevalent in winter, mostly between November and March, in conjunction with the passage of cold Cyprus Lows over the relatively warm water of the Mediterranean Sea. Thunderstorm cells are 6-8 km in height and are often found in cold-fronts and within the ensuing cloud streets, and are sometimes accompanied by Transient Luminous Events. The ILAN campaigns (Imaging of Lightning and Nocturnal Flashes) have been conducted continuously since 2004, monitoring the properties of the TLEs associated with thunderstorms in Israel and its vicinity. The optical observations have been conducted from the Tel-Aviv University campus and from the Wise Astronomical Observatory at Mitzpe Ramon in the Negev desert, at first alternating between sites and later simultaneously. The optical campaigns were accompanied by ELF and VLF data and lightning location systems. We will review the statistical data obtained in 7 winter campaigns (2004/5-2012/13), describe the properties of sprites and of other TLEs, and analyze their dependence on the properties of their parent flashes. A comparison to similar winter storms in Japan and Europe reveals similarities and differences in the properties of winter TLEs.

キーワード: Winter thunderstorms, Lightning, Transient Luminous Events, Sprites, Optical observations

Keywords: Winter thunderstorms, Lightning, Transient Luminous Events, Sprites, Optical observations

ELF 帯誘導磁場測定による落雷電流波形推定 Estimation of lightning current waveform from ELF magnetic induction field

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New project to estimate lightning current waveform from ELF magnetic field observation is introduced. A positive GC lightning event in winter was detected by a Rogowski coil at Mt. Ogami, Niigata Prefecture, Japan on Jan. 2010. The peak current and the electric charge were 26 kA and about 1 kilo-coulomb, respectively. Electromagnetic radiation from the lightning was measure by Lightning Location System (LLS) in Tohoku district and ELF magnetic field observation at Onagawa observatory, Miyagi Prefecture. Although only pulse series' were radiated in LF, a horizontal magnetic field waveform resembling the current waveform was observed in ELF. At the distance of Onagawa (296 km apart from Ogami), the ELF waveform should resemble that of the source current because the ELF signal is mostly composed of the induction components. This means the ELF signal has potential to use direct estimation of current waveform of any lightning discharge as well as the amount of electric charge causing damage to grounded structures. Comparisons of waveforms between the current and ELF have done for several lightning events to find the statistical properties. New observation site is planned in Kyushu distinct with a cooperation of ICSWSE, Kyushu University.

アジア雷放電観測網構築と気象現象への応用 Construction of lightning observation network in Asia and its applications to meteorology and climate studies

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SE-Asia is one of the most important regions in the world, which is closely related to the important meteorological phenomena, such as Madden Julian Oscillation, El Nino, etc. Also very severe weathers sometimes happen in this area, which leads to loss of human lives and estates. Therefore, monitoring and understandings of atmospheric activities in this region is quite important. However, it is not easy only with existing observation equipments and the limited number of advanced facilities such as expensive meteorological radars. Lightning observation in frequency range of VLF would be a very effective methodology to monitor the activity of thunderstorms which are the drives global atmospheric circulation and may cause significant disasters. We have been developing Asia VLF observation network: AVON, which now consists of 3 stations located at Taiwan, Thailand and Indonesia. The geolocation will be carried out by time-of-arrival method with an error of 10 km. From AVON data, we could estimate the charge moment change of the lightning stroke, which might be a good proxy of meteorological parameters in thunderstorm. In order to improve the accuracy of geolocation and to achieve the redundancy, we plan to add 2 or 3 more stations in SE-Asian countries, such as Philippines, Vietnam. Here we discuss the scope of AVON observation including various possibilities of applications to meteorology and climate studies.

キーワード: 雷放電, 東南アジア, 観測網, 気象, 気候
Keywords: lightning, SA-Asia, AVON, meteorology, climate

アジア VLF 観測ネットワーク (AVON) および日本の VLF/LF データを用いた雷への D 領域電離圏応答

Response of the D-region ionosphere to lightning using Asia VLF observation network (AVON) and VLF/LF data in Japan

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It is known that the electromagnetic pulse (EMP) originated from cloud-to-ground and inter-cloud lightning discharges can couple directly into the D-region ionosphere. The conductivity in the D-region changes due to the EMP. When VLF/LF waves propagate under the disturbed D-region, the amplitude and phase or the reflection height of the VLF/LF waves varies largely. For example, 'early VLF events' show large variations in amplitude and phase and are caused by the coupling between the D-region and lightning. Early/fast events, early/slow events, and long recovery events are included in the term of 'early VLF events'. The descent (rise) of VLF/LF reflection height corresponds to increase (decrease) in electron density in the D-region. We have conducted Asia VLF observation network (AVON) in South-East Asia: Taiwan, Thailand, Indonesia, Philippines, and Vietnam since 2007. The observations in Taiwan, Thailand, and Indonesia are performed at present, while we will construct a new observation system in Philippines in February, 2013. We also have a plan of a new observation system in Vietnam after the Philippine construction within 2013. The aim of the AVON is to monitor the lower ionosphere and lightning in South-East Asia. We observe North-South and East-West broadband magnetic components with loop antennas, a vertical broadband electric component with a dipole antenna, and amplitude and phase of narrowband LF transmitter signals with a monopole antenna. We investigate the VLF/LF perturbations associated with the lightning discharges using both the AVON data and the VLF/LF data observed in Japan. In the presentation, we show several early VLF events and discuss the coupling between the D-region and lightning.

関東地方における VLF 帯雷電磁波観測データを用いた落雷規模の推定 Estimation of lightning magnitude using VLF sferics in Kanto region

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It is pointed out that the relationship between atmospheric parameters and occurrence frequency of lightning is closely correlated. By the current lightning detection systems operated in Japan, which measure higher frequency than VLF range, only the information of peak current of the stroke is estimated and information of its magnitude, such as charge moment change (CMC) cannot be derived. Since the most of the electromagnetic energy of lightning concentrates in the frequency range less than 10 kHz, in order to estimate CMC of lightning stroke, we need to observe the electromagnetic waves in lower frequency range than existing lightning networks which make use of order of several 10s of kHz to M Hz range. Carrying out the continuous observation of VLF sferic, we will investigate the quantitative relationship between atmospheric parameters and lightning activity including information of electrical magnitude for the first time.

We are constructing a VLF observation network with identical observation system, consisting of three observation sites in Kanto region, which enables us to geolocate lightning stroke by time of arrival (TOA) or direction finding methods with an error of 10 km. Each observation system is composed of two horizontal magnetic loop antennas and a vertical electric dipole antenna, receiver, PC and GPS clock. The higher cutoff and sampling frequency are 40 kHz and 80 kHz, respectively.

In order to estimate CMC, the temporal variation of source current with peak intensity is required. We estimated the peak current using a method proposed by Yanagi [2012]. The temporal variation of source current was estimated from the groundwave of electric field, using amplitude and zero-crossing time of the waveform.

In this presentation, we will report the situation of construction of this observation network and the estimation methodology of lightning peak current using sferic data. Also preliminary results based on the data obtained at Yamanashi station are introduced.

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Yanagi, Y., Development of VLF electromagnetic wave observation system and estimation method of lightning peak current, Master thesis, Hokkaido University, 2012.

Keywords: lightning, charge moment change

アジア海洋大陸の雷活動と熱帯域のOLRの時間同期

Synchronization between lightning activity in the Maritime Continent and OLR in tropics

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Lightning activity is an excellent proxy of atmospheric circulation in thunderstorm. Therefore, the research of global lightning activity leads to understanding of the global atmospheric circulation. However, there has been no objective global lightning data set. We have developed and been operating the global ELF observation network named GEON. Yamashita et al. (2011) analyzed GEON data recorded in the period of August 2003- July 2004 and estimated location and charge moment change of each lightning stroke with uniform sensitivity over the world for the first time.

We performed correlated analysis between the number of the lightning strokes derived from GEON and Outgoing Longwave Radiation (OLR) in the tropical regions, focusing the variation with about month periodicity.

It was found that the number of lightning strokes in the Maritime Continent (MC) varies with about month periodicity in the period from February to June 2004 and shows positive correlation ($R \sim 0.8$) with OLR in the Western Pacific Warm Pool (WPWP). That is, when thunderstorm activity in the MC is enhanced, the OLR in WPWP becomes large, meaning less cloud amount. On the other hand, OLR in the central Africa shows negative correlation with the number of lightning strokes in the MC in that period ($R \sim -0.7$). Furthermore, in the central Africa OLR seems to reflect the number of lightning strokes, showing good correlation between them. This implies that the activities of thunderstorms both in the central Africa and in the MC oscillate in the same phase. Also OLR in the central of Pacific Ocean, America and the Atlantic Ocean show negative correlation ($R \sim -0.6$). In the central of Pacific Ocean and the Atlantic Ocean, OLR shows low amplitude except the period of negative correlation. Such a synchronization of thunderstorms or cloud amount in global scale without phase difference has not been reported.

キーワード: 雷活動, GEON, OLR, アジア海洋大陸, テレコネクション

Keywords: lightning activity, GEON, OLR, Maritime Continent, teleconnection

ハイスピードカメラ観測によるスプライトストリーマの分岐条件 Split Condition of Sprite Streamer Tips Derived From High-Speed Camera Observations

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In order to clarify the split condition of sprite streamer tips, the detailed spatial and temporal development of sprite streamers are the key physical properties. According to the previous ground-based observations using high-speed cameras, it was found that streamer tips usually appear at around ~80 km at the initial stage of the sprite development and propagate downward with an accelerated and expanded motions. After they reach ~70 km altitude, they tend to start splitting. However, detailed splitting mechanism of streamer tips is not fully understood yet since it is difficult to capture the detailed development and fine structures of the splitting streamer tips. In order to specify the detailed spatiotemporal evolution of sprite streamers and to identify the physical parameters determining the splitting condition of streamer tips, we have analyzed image data obtained by high-speed cameras onboard two jet aircrafts.

In the period from June 27 to July 10, 2011, we have succeeded in capturing 12 sprite events over the Great Plains in summer US, where the multiple splits of streamer tips are clearly measured by high-speed cameras with a sampling rate of 8300 fps. It was found that streamer tips initiated from approximately 75 km altitude propagate downward with an exponential increase of the brightness before they start splitting first. We estimated brightness changes of streamer tips at each frame of image data recorded by the high-speed cameras, and we also estimated the ratio of the streamer tip brightness just after the tip splits to that just before the tip reaches next split. It is found that the ratio of the brightness at the streamer tip initiation to the brightness just before the first split becomes greater than 1.0. However, it is found that the ratio of the brightness of 1st (2nd) split to 2nd (3rd) split becomes about 1.0. At the presentation, we will show more detailed results.

東北地方における冬季雷活動の統計的特徴 Statistical Features of Winter Lightning Activity in Tohoku District

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東北や北陸地方の日本海側では、10月以降の寒候期に雷活動が活発化するという世界でも珍しい地域性を有している。特に12月以降の厳冬期に発生する「冬季雷」は、一般的な夏の雷と比較して一放電あたりの電流量が高く(e.g. Hojo et al., 1989)、しばしば日本海沿岸域における電気工作物(送電線や風力発電設備等)に被害をもたらすことから、深刻な問題となっている。また近年、冬季における雷日数は増加傾向にあることも指摘されている(藤部他, 2005)。

冬季雷活動に関する電氣的・気象学的研究はこれまでも活発に行われており、雷雲の電氣的構造(e.g. Kitagawa and Michimoto, 1994)やレーダーエコーとの関係(Michimoto, 1993)、当該地域における詳細な落雷密度分布(藤沢, 川村, 2005)などが明らかにされてきた。しかし、これら先行研究の多くは主として厳冬期の北陸地方を対象にしたものが多く、東北地方は冬季雷のホットスポットの一つであるにもかかわらず、十分な調査が進んでいない。

本研究では、東北電力(株)が有する落雷位置標定システム(LLS)により計測された過去17年間(1994~2011年)の落雷位置情報を統計し、東北から北陸地方東部における寒候期(10月~翌年3月)落雷頻度分布の特徴と、その季節変化や年々変動に関する調査を実施した。冬季雷放電に対するLLSの落雷位置標定精度は約2km、捕捉率は約63%程度と見積もられている(Honma et al., 1998 and Honma, 2010)。

解析の結果、対象地域の多くの地点において旬積算落雷数の最大値は10月上旬から11月下旬にかけて発現することが分かった。落雷頻度分布の季節変化については、晩秋(10~11月)から冬季(12月以降)にかけて落雷頻度の極大域が南下し、季節の進行とともに落雷点が海岸線のごく近傍に集中する傾向が捉えられた。

また過去17年間における落雷頻度の経年変化を調べたところ、平年に比べて落雷頻度の高い年度が4~6年おきに発生していた(1997, 2002, 2006年度)。これらの年度はいずれも冬季~春季にかけてEL-Ninoとなっており、南方振動(ENSO)による冬季雷活動への影響が示唆される。しかし2009年度はEL-Nino年であるにもかかわらず落雷頻度は平年並みであり、ENSOと雷活動との関係は必ずしも明確ではない。

キーワード: 冬季雷, 落雷位置標定システム

Keywords: winter lightning, Lightning Location System

電荷モーメント情報を含む全球落雷情報の解析 Global lightning distribution with information of charge moment change

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Lightning is an electrostatic discharge phenomenon in the atmosphere. Primarily there are three types of discharges, namely, cloud-to-cloud discharge (CC), intra-cloud discharge (IC), and cloud-to-ground discharge (CG). Further, CGs are classified into two types: positive and negative polarities. Charge moment change (Qdl) is one of the parameters representing the significance of lightning discharge. In this study, base on the analysis of lightning waveform observed by global ELF observation network (GEON) we constructed an empirical model of the Qdl distribution, by fitting simple curves to the observational datasets for almost all the Qdl range, that is, from 0 to 3000 C-km. We examined the characteristics of the Qdl distribution in 7 regions where lightning activity is quite high, namely, Maritime Continent in Asia, Australia, Central Africa, South Africa, North America, South America, and South Pacific. The results show a large variation of the distribution depending on the location, season and current polarity. This empirical model of the Qdl distribution can be applied to various purposes, such as an estimation of global circuit current and comparison with meteorological parameters.

キーワード: 雷放電, 全球分布, 電荷モーメント, 経験モデル

Keywords: lightning, charge moment change, global distribution, empirical model