大気電場の太陽活動に対する応答
Dependence of atmospheric electric field on solar activity

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The vertical atmospheric electric field variations depend on the state of the global circuit. Under the fair weather condition, atmospheric electric field directs vertically downward. The direction is due to the electric potential in the ionosphere and the Earth’s surface. Thus ionospheric state seems to affect atmospheric electric field.
Kleimenova et al. [2010] examined atmospheric electric field at the time of substorms. They concluded that the deviations of Ez at high latitudes are the result from an enhanced polar convection or change in the ionospheric potential.
Since the report was established based on high-latitude data, we focused on low-latitude atmospheric electric field variation related with ionospheric state. In this study we analyzed the low-latitude atmospheric electric field Ez at KAK (G.G. Lat.: 36.2 N, G.G. Lon.: 140.2 E) and solar F10.7 index which is derived from solar radio flux at a 2.8 MHz. The solar F10.7 flux is well known that related with ionization in the ionosphere through solar extreme ultraviolet (EUV) emission. Daily Ez amplitude for high solar-activity (F10.7 > 100) periods shows higher value than that for low solar-activity (F10.7 < 100) periods. The tendency is predominant in July and August. When solar EUV flux is intense, ionization in the ionosphere are promoted and ionospheric potential becomes higher. We, therefore conclude that potential difference between the ionosphere and the Earth’s surface becomes larger and the atmospheric electric field is enhanced during high solar-activity periods.

キーワード：大気電場、太陽活動
Keywords: atmospheric electric field, solar activity

Prediction of Nighttime VLF Signal Amplitude for Mid-and High-Latitude Paths

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The amplitude of Sub-ionospheric Very Low Frequency (VLF) propagation is sensitive to the lower ionospheric. Accordingly, VLF waves have been proposed to study and monitor the lower ionospheric conditions. However the temporal dependence of VLF amplitude has complicated and large daily variabilities in general due to combinations of both effects from above (space weather effect) and below (atmospheric and crustal processes) of the ionosphere. Thus the modelling and prediction of VLF wave amplitude are important issues to study the lower ionospheric responses from various external parameters and to also detect the anomalies of the ionosphere.
In this paper, the NARX (Nonlinear Autoregressive with Exogenous Input) neural network is used as a novel method for predicting daily nighttime averaged amplitude of VLF transmitter signals indicating the ionospheric perturbation around the transmitter-receiver path. The NARX neural networks has a good accuracy in predicting time series data and thus are more suitable for dynamic modelling. The NARX model, which was built based on daily input variables of various physical parameters such as stratosphere temperature, cosmic rays, total column ozone, K-index, AE-index and Dst, possessed good accuracies during the model building. The NARX model for VLF transmitter in Hawaii, USA (NPM) and receiver in Chofu (CHF) Tokyo, Japan (mid-latitude path), which was constructed based on above mentioned. In addition, the high-latitude path from the transmitter in Washington, USA (NLK) to receiver in Chofu (CHF) Tokyo, Japan, which was built as well.
As a result, the constructed models are capable of performing accurate one step (1 day) ahead predictions of the nighttime VLF amplitude from January 1st, 2011 to December 31st, 2013 for NPM-CHF path with the Pearson correlation coefficient (r) of 0.93 and with Root Mean Square Error (RMSE) of 2.0 dB and also the results for multi-step ahead 5 days prediction (r = 0.86, $RMSE$ = 1.88) and multi-step ahead 10 days prediction (r = 0.74, $RMSE$ = 2.35). Furthermore, result for NLK-CHF path with r of 0.91 and RMSE of 2.64 dB. In addition, we will demonstrate multi step ahead prediction of daily nighttime VLF amplitude for NLK-CHF paths. We conclude the model built according to the proposed methodology provides accurate predictions of the electric amplitude of VLF wave for both NPM-CHF and NLK-CHF propagation paths.

Keywords: very low frequency, VLF transmitter, nonlinear autoregressive with exogenous input, one-step ahead prediction, multi step ahead prediction

北陸冬季雷が下部電離圏に及ぼす影響

Lower ionosphere perturbations caused by Hokuriku winter lightning

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Intense electromagnetic pulses (EMP) radiated from lightning discharge could cause heating and ionization in the ionospheric D-region. While theoretical studies show that change in ionization state in the D-region depends on intensity of EMP, there is no clear observational evidence that shows quantitative relationship between them. The purpose of this study is to reveal influence of the CG(Cloud-to-Ground) and GC(Ground-to-Cloud) lightning discharges on the D-region and to confirm theoretical predictions by observation. The change in ionization state in the D-region is detected using perturbation in low frequency (LF) manmade radio waves which propagate in an earth-ionosphere waveguide. For this purpose, LF radio observation system was installed in Takine (Fukushima Pref.) and measured radio signal from JJY transmitter(60kHz) at Mt. Haganeyama. The midpoint of radio propagation path is located over the coast of Hokuriku area. This enables us to investigate Hokuriku winter lightning effect on the lower ionosphere near the 1-hop point of LF radio propagation. Distance between Takine and Mt. Haganeyama is 1045km and the 1-hop theory is well applicable to predict signal phase at the receiver. The LF sub-ionospheric perturbations which are called as early events have been observed from December 12, 2014 to March 31, 2015. World-Wide Lightning Location Network was used to identify lightning location and timing during this period and totally 189 sets of sub-ionospheric perturbation and causative lightning were detected. A peak current of causative lightning which is a proxy of the EMP intensity was derived from LF atmospherics observation at Suzu (Ishikawa Pref.). Charge moments of the lightning were also derived from ELF magnetic field observation at the Syowa station (Antarctica). The charge moments derived were distributed from 200 to 500 C-km and suggest that quasi-electrostatic field was lower than breakdown threshold at the lower ionosphere and was not responsible for producing sub-ionospheric perturbation observed. Modeling studies predict that EMP produced from a CG discharge creates torus-shaped ionization pattern around 90km height above a causative lightning and horizontal scale depends on intensity of EMP. We statistically examined sense of the phase change as functions of strength of EMP and distance of causative lightning from the 1-hop point along radio propagation path. Based on the 1-hop theory, positive and negative changes in the phase correspond to downward and upward shifts of radio reflection height, in other words, increase and decrease in ionization in the lower ionosphere near the 1-hop point, respectively. Result shows that sense of the phase change strongly depends in both strength of EMP and distance of causative lightning from the 1-hop point; (1) phase increase (which correspond to the ionization increase) was found when a distance between a causative lightning and the 1-hop point was within 100km and the peak current was smaller than 200kA. The distance increased up to 150km when the peak currents were larger than 200kA. This shows that ionization area extends further due to more intense EMP. (2) Outside of these distances, on the other hand, the phase decreases (which correspond to the ionization decrease) was found. Intensity of EMP degreases as distance from a causative lightning.

When the electric filed strength becomes lower than the breakdown threshold, electron attachment rate dominates ionization rate, causing decrease in ionization state. (3) Less occurrence of sub-ionospheric perturbation was found inside the distance of 20km from the 1-hop point compared to the surrounding area. This suggests that EMP does not affect ionization state in the lower ionosphere just above CG/GC discharge. These results are consistent with the theoretical expectations.

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キーワード：雷放電、電離圏D領域、early event
Keywords: lightning discharge, ionospheric D-region, early event

冬季雷雲のガンマ線測定を狙う多地点観測システムの新規開発

Development of a new multipoint observation system for gamma-rays from winter thunderstorm

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日本海沿岸の冬季雷雲から 10 MeV に達するガンマ線が地上に放射されていることが観測的に知られており (Torii et al., 2002, Tsuchiya & Enoto et al., 2007)、雷雲内の強電場により電子が相対論的な領域まで加速されていると考えられている。これまでの観測では単地点の観測が多く、電子加速域の生成・成長・消失を追跡を追うことは難しかった。そこで我々は、雷雲の流れにそって複数の観測点を設けたマッピング観測を行うことで、放射の始まりと終わりを確実に捉え、ガンマ線強度やスペクトル変化を測定し、加速現象の全貌を明らかにすることを狙っている。冬季雷雲の平均的な移動速度は ~500 m/ 分で゛、単点観測で゛数分にわたりｶﾞﾝﾏ線増大が゛検出されるため、およそ数 km 間隔で゛約 20 個ほど゛の観測サイトを設けることを考えている。そこで、CsI や BGO シンチレータ、プラスチックシンチレータと独自に開発した回路基板、小型のコンピュータ Raspberry Pi を組み合わせ、30 cm 立方ほどの可搬型の放射線検出器を開発し、金沢大学と金沢大学附属高校に設置して観測を開始した。個々の放射線イベントの到来時間とエネルギー、温度などの環境情報を収集してる。今後、観測地点を増やして、マッピング観測を行いたい。なお、本プロジェクトは、民間の学術系クラウドファンディングからの寄付金によるサポートも得ておこなわれた。

キーワード：冬季雷雲、ガンマ線、電場、電子加速
Keywords: winder thunderstorm, gamma-ray, electric field, electron acceleration

落雷時に生じる制動X線の直近観測

Lighting-induced bremsstrahlung X-rays observed near the leader.

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Energetic radiation, bremsstrahlung X ray in energy range of gamma ray, associated with lightning activities and thunderstorm have been reported. The lifetime of lightning-generated X rays, termed short burst, is in the order of millisecond. These X rays are considered to be generated by bremsstrahlung along the leader, termed short burst. During the winter, the bright short burst with more than 100 millisecond duration was detected on 4 Dec. 2015. In this analysis , we compare radiation data with VLF lightning location data and high speed camera data.

キーワード：高エネルギー放射線、冬季雷、雷雲
Keywords: Energetic radiation, Winter Lightning, Thunderstorm

VHF広帯域干渉計による多地点落雷の放電路進展様相

Cloud-to-ground flashes with multiple strokes observed by Broadband Digital Interferometer

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かつて複数の雷撃が同じ放電路を通って起こる多重落雷と考えられていた現象の中に、僅かの時間間隔で別の地点に落雷する多地点落雷が存在することが確認されている。多地点落雷は、送電線の雷故障現象を複雑化し、故障点発見や故障解析を困難なものとする。本稿では、その性状や発生過程を明らかにすることを目的として、岐阜県東濃地方において筆者らが行っている雷観測のうち、平成26年度の夏季に干渉計により放電路が良好に可視化され、同時に LLS（Lightning Location System） によるデータ取得に成功した多重または多地点落雷の放電路解析を行う。ここで、本稿における「多地点落雷」は、一連の雷放電内で、雷撃点が先行する雷撃と異なる後続雷撃を含む雷放電現象を指す。
干渉計、LLSで同時に観測された多重または多地点落雷は13例で、そのうち6例が多重落雷、2例が多地点落雷、5例が多重落雷と多地点落雷の両方の性質を含むものであった。ここから得られた注目すべき特徴は以下の通りである。
・リーダが枝分かれして進展し、その一方が大地に至った雷撃の数十ms後、先行するリーダのうち雷撃に至らなかった放電路をダートリーダが進展し、さらにその続きをステップトリーダが新たに進展して大地に至る多地点落雷が確認された。
・多地点落雷のあとの後続雷撃が一つ前の放電路を通らずもう一つ前の雷撃路を通る落雷があることが確認された。
・先行するステップトリーダと同じ放電路を通り同じ地点に落雷するが、一部新たな放電路を進展するダートリーダがあることが確認された。
・4地点に及ぶ雷撃が観測された。
・多重落雷か多地点落雷かは、雷撃時間差のみに因るものではない。

キーワード：雷放電、多重落雷、広帯域ディジタル干渉計
Keywords: lightning discharge, multiple storke, broadband digital interferometer

落雷位置情報を用いた雷雨領域の高時間分解能推定
Highly time resolved tracking of the torrential rain from lightning data

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Previous studies suggested that there exists a good relationship between frequency of lightning and atmospheric convection or precipitation [e.g. Deierling and Petersen, 2008]. Therefore, lightning data can be used as a proxy for the presence of deep atmospheric convection and precipitation. To monitor time series behavior of lightning activity, it is possible to understand more detailed relationship between the lightning activity and atmospheric convection and it is also possible to predict the distributional area of precipitation.
Our purpose of research is to estimate rain activity by the information of cloud to ground (CG) lightning discharge location. Therefore, we compare the movement of the torrential rain area with the lightning cell by a calculation of a time variation of the CG lightning frequency and that of spatial distribution of lightning.
We analyzed 3,909 events of CG lightning from 14:00, August 11th 2013 to 15:29 (JST) and 3,693 events of CG lightning from 17:30, August 12th 2013 to 19:24 (JST) observed by Japan Lightning Detection Network (JLDN) in Kanto region to estimate the frequency and spatial distribution of CG lightning for 10 min and with 1km square grid. We use the C-band rain radar data provided by the Japan Meteorological Agency (JMA) as the data of rain intensity. The temporal and spatial resolutions of the data are 10min and 1km.
As a result of comparing spatial distribution of lightning with that of precipitation, it is possible that there is a good correlation between the CG lightning distributional area with torrential rain area (>50mm/h) and it is possible that we can estimate the torrential rain area (>50mm/h) to monitor the time variation of the CG lightning frequency and that of spatial distribution of lightning.
We calculated the cross correlation function between the CG distribution at a certain time and that of the one 1 later in order to estimate the motion vector of CG area and we required the luminance centroid to track CG lightning area. We also calculated the cross correlation function between the torrential rain area (>50mm/h) at a certain time and that of the 10 minute later in order to estimate the motion vector of rain area and we required the luminance centroid to track rain area.
As a result of comparing the lightning luminance centroids and that of precipitation, we can estimate the luminance centroid of the torrential rain area (>50mm/h) with an accuracy of 2km by using the luminance centroid of lightning distributional area and it is possible that we can estimate the motion of the torrential rain area with highly time resolution by CG lightning data.
In this presentation, we will discuss the adequacy of analysis method and our initial result. Also we will consider the relationship between the distributions of the CG lightning frequency and torrential rain area.

キーワード：雷、対地雷撃、雷セルトラッキング
Keywords: Lightning, Cloud to ground lightning discharge, Tracking of the lightning cell

フェーズドアレイレーダーと雷放電の三次元観測により得られた積乱雲内の電荷構造と鉛直流の関連
Relationship between charge structure and vertical air motion in a thunderstorm revealed by a phased array weather radar and 3D lightning mapper

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Thunderstorm observation has been conducted in Osaka, Japan, with a use of an X-band phased array weather radar (PAWR) and a 3D lightning mapper, called Broadband Observation network for Lightning and Thunderstorm (BOLT), for further understanding of relationship between electrification mechanism and vertical air motion, which plays an important role in non-inductive charging process. PAWR employs mechanical and electrical scans, respectively, in azimuthal and elevation direction, succeeding in quite high volume scan rate. BOLT is a LF sensor network that receives LF emission associated with lightning discharges and locates LF radiation sources in 3D. BOLT is capable of estimating charge structures removed by both intra-cloud (IC) and cloud-to-ground (CG) flashes. In this presentation, we focus on lightning activity and charge structure in a convective cell recorded on 30 July 2015. The convective cell involved severe lightning activity in 15 minutes and the both IC and CG flash rate (the number of flash per minute) changed drastically within the 15 minutes. We divide the 15 minutes lightning activity into three stages; the first, the second and the last 5 minutes, respectively, are termed developing, mature, and dissipating stages, based on IC and CG flash rates. In the developing stage, IC flash rate increased drastically from a few to about 10 flashes min^{-1}. In the mature stage, IC flash rate are quite high and had a peak of 12 flashes min^{-1}, while CG flash rate increased gradually. In the dissipating stage, IC flash rate drastically decreased, while CG flash rate had a peak of 5 flashes min^{-1}. In the developing stage, updraft in the mid-level (about 7 km) developed into the upper level (10 km or more in AGL). In this presentation, we estimate existence of updraft from Doppler velocity and ascending echo. The echo top of the convective cell increased rapidly. The main positive charge region estimated by BOLT was located around the updraft region in the upper level. In the mature stage, the updraft was further intensified and the echo top reached the tropopause altitude of 14.5 km. The main positive charge region was again located in the updraft of the upper level. In the dissipating stage, divergence at the echo top produced cold downdraft in the rear flank of the convective cell. The cold downdraft descended to mid-level (about 7 km) and suppressed the updraft at mid-level so that the updraft in the upper level was weakened. These observation results indicate a strong relationship between electrification for IC discharges and updraft strength. In the dissipating stage when CG flash rate peaked, main negative and pocket positive charge regions estimated by BOLT were located near the mixture region of the cold downdraft and updraft from the lower level. We speculate that the pocket positive charge region was mainly produced by the collisions between graupel in the downdraft originated form in the upper level and the ice pellets ascending form the lower level. These simple speculation support that non-inductive charging mechanism in thunderstorms.

キーワード：雷放電、上昇気流、電荷構造
Keywords: lightning, updraft, charge structure

固定型二重偏波フェーズドアレイレーダにおける観測精度の検討
Study of observational accuracy of non-rotating dual-polarization phased array radar

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近年，集中豪雨や，竜巻など突発的な気象現象が問題となっている．数分規模で変化していく雨雲の内部構造の進展，発達を補足し予測・対応していくためには，より高い時空間分解能(数十秒程度)を持つ気象レーダによる観測が求められる．2012年に高時間(30[sec])分解能かつ高空間分解能(100[m])を持ち合わせたX帯フェーズドアレイレーダ(PAR)が開発されたが，現在のPARは単一偏波(水平偏波)のみでの観測であるので，直交二偏波を用いる二重偏波レーダと比較するとその観測精度は低い．よって，今後開発が期待されるレーダとして，高速スキャンと高精度観測の二つを実現する二重偏波フェーズドアレイレーダがあげられる．しかし，ディジタルビームフォーミングを行うことによるアンテナ特性の劣化や，直交二偏波を区別する性能である交差偏波識別度(XPD)の低下などの問題により，二重偏波フェーズドアレイレーダは実用化されていない．本稿では，これらの問題を解決するためにアンテナ素子の設計および平面型，円柱型，球型の三種類の固定型アレイの形状を設計し，降雨観測のシミュレーションを行い，その結果に対する考察を行う．

キーワード：フェーズドアレイレーダ、二重偏波、降雨観測
Keywords: phased array radar, dual-polarization, pricipitation observation

偏波フェーズドアレイレーダの開発とビーム形成に関する検討
Development of a polarimetric phased array weather and adaptive beamforming technique

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Development of a polarimetric phased array weather radar as a subsequent project of the phased array weather radar (PAR) is under discussion. The design of a polarimetric phased array weather radar has been the object of several experimental development. The polarimetric phased array weather radar has significantly advanced the following points. 1) to classify types of precipitation, 2) to provide quantitative estimates of precipitation accumulation, 3) to obtain high spatial and temporal resolution volumetric radar data. 1) and 2) are contributed by a polarimetric sensing technique, and 3) is provided by the digital beam forming techniques in a phased array radar system. In this paper, precipitation radar signal simulations based on the under considering radar concept are carried out to discuss the estimation accuracy of polarimetric precipitation profiles (differential reflectivity, specific differential phase, and copolar correlation coefficient) with two DBF methods that are based on Fourier and minimum mean square error (MMSE) methods. The comparison of the performance of the two methods indicates that MMSE is superior in an observation accuracy because of the effect of a stable and robust main lobe and adaptively suppressed side lobes.

キーワード：気象レーダ、フェーズドアレイアンテナ
Keywords: weather radar, Phased array antenna

二重偏波レーダネットワークにおける降雨減衰補正手法の開発

Development of precipitation attenuation correction technique in a dual-pol radar network

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竜巻や突発的な集中豪雨等のシビア現象によってもたらされる自然災害の発生が近年増加傾向にあり，低層の降水情報に対する迅速かつ正確な把握の必要性から，X帯二重偏波レーダネットワークによる気象観測が近年主流となっている．X帯二重偏波レーダネットワークによる観測で得られるレーダ反射因子差Z_{DR}，比偏波間位相差K_{DP}，偏波間相関係数ρ_{HV}等の偏波パラメータにより，単一偏波観測では知り得なかった上空の降水粒子判別，雨滴粒径分布推定，降雨量推定が可能となっている．
偏波パラメータの一つであるK_{DP}は前方散乱の偏波間位相差の積算量ϕ_{DP}を距離微分した値として算出されるが，実際に観測される位相差ψ_{DP}は，観測レンジにおける後方散乱によって生じる位相差δ_{co}を含んだ値となっており，強雨域でδ_{co}が非ゼロの値を持つX帯において，K_{DP}の算出にはδ_{co}の除去が不可欠である．また，X帯では強雨域において激しい降雨減衰が発生する事が問題となっており，Z_{DR}もその影響を受けて減衰する．現在K_{DP}やϕ_{DP}を用いた減衰補正が用いられているが，正確な降雨減衰補正のためには正確なδ_{co}の除去が必要となる．
δ_{co}とZ_{DR}は強い相関を持つ事が知られており，単体レーダにおいてこの関係を用いてδ_{co}を再帰的に除去するアルゴリズムは提案されているが，アルゴリズム内における関係式の係数値は固定されており，雨滴粒径分布によって変化する事が考慮されていない．本研究では，二重偏波レーダネットワークにおけるδ_{co}の影響を考慮したZ_{DR}の減衰補正手法について検討した．

キーワード：気象レーダ、雨
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フェーズドアレイ気象レーダー（ＰＡＷＲ）を利用した極端気象現象（落雷、降雹等のシビアハザード）予測に関する研究

The prediction method of sever hazards(Lightning strikes, Hails, etc.) by using Phased Array Weather Radar(PAWR)

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予測が困難な局地的大雨（いわゆる「ゲリラ豪雨」など）が引き起こす、河川の氾濫や洪水などの災害軽減のためには、防災（気象などの）情報が有効である。本研究では、新型気象レーダー（PAWRと略記）などから得られる、いわゆるソーシャル・ビッグデータから、防災（気象）情報を導出する方法に関する研究を実施する。すなわち、「ＰＡＷＲ」や「ひまわり８号」などからの膨大なデータを用いた高密度の気象予測の基本技術を確立するための基礎的な解析研究を実施する。

キーワード：フェーズドアレイ気象レーダー、落雷、降雹
Keywords: Phased Array Weather Radar, Lightning strikes, Hails

