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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