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VHF observations of positive cloud-to-ground lightning flashes in summer thunderstorm season

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Positive cloud-to-ground (CG) lightning flashes are defined as those lowering positive charge from cloud to Earth. It is thought that less than 10 percent of global CG flash is positive. Positive CG flashes have attracted considerable attention for the following reasons. 1) The high lightning current and large charge transfers to ground. 2) They can be the dominant type of CG flashes in winter season and during the dissipating stage of thunderstorm. 3) They are related preferentially to transient luminous events (TLEs) in the middle atmosphere like sprites. 4) Reliable identification of positive CG flashes is important implications for various lightning location techniques.

The authors have been conducting cooperative lightning observations in Gifu, Japan, where occupy a lot of hill and mountainous region. Chubu Electric Power Co., Inc. (CEPCO) have has many (over 1.0 cases / 100 km / year) outages in their 500 kV power transmission line caused by lightning. This paper focuses on positive CG flashes observed by a VHF lightning mapper, Broadband Digital Interferometer (DITF) and Lightning Location System (LLS).

DITF is a system to locate a source of VHF impulse based on the digital interferometric technique. A remarkable feature of DITF is its wide detection frequency range, and this system takes no account of a carrier frequency. The system observes the electric field change due to a lightning discharge in the ultra-wide VHF band, and Fast Fourier Transform (FFT) is applied to calculate various frequency components of the received electromagnetic (EM) pulse. Computed phase difference for each Fourier component between two antennas is a function of the incident angle of the EM pulse against the baseline. A couple of antennas as a two-element array of DITF are able to estimate the incident angle. Two pairs of antennas, and independent two baselines, enable two-dimensional (2D) mapping of sources in azimuth and elevation format. Synchronized operations of two or more DITFs with proper separations can bring three-dimensional (3D) source locations by a triangulation.

It is known that VHF impulses are mainly radiated from the tip of breakdown like at the stepped leader tip especially in case of negative breakdown. In case of a negative CG flash, ordinary downward propagating leaders can be shown by DITF. In case of positive CG, radiation source locations do not go downward straightforward to the ground. They sometimes show the tendency of concentration at certain and qusi-constant altitude of the possible positively charged region. According to the bi-directional leader concept, a lightning discharge is initiated with both positive and negative leaders progression simultaneously in opposite directions from its original inception point. The origin of a lightning discharge is normally not to be grounded to the earth, and the bi-directional leader progression should be trivial form the aspects of the charge conservation law. Since the average intensity of VHF radiation by a positive breakdown was about 20 dB weaker than that by a negative breakdown, positive breakdowns masked by the radiation emitted by negative breakdowns are considered to be undetectable by DITF. Active VHF radiation after a return stroke may be mainly due to the continuing currents, because the continuing current is caused by the negative breakdown progression inside the thundercloud.

Four positive CG flashes are observed both a pair of DITFs and LLS in this study. A multiple positive CG flash, a downward positive leader overlapping with upper negative breakdown, a positive CG flash lowering low-altitude small positive charge like pocket positive, and positive CG flashes without any VHF radiation before the return strokes are noticeable.

Keywords: Positive cloud-to-ground lightning flash, Broadband digital interferometer, Lightning Location System, lightning in summer season