Charge structures indicated by lightning discharge locations in Hokuriku’ s winter thunderstorms

*Dong Zheng[1], Daohong Wang[2], Yijun Zhang[3], Ting Wu[2], Nobuyuki Takagi[2]

1. LaSW, CAMS, 2. Gifu Univ., 3. Fudan Univ.

Using three-dimensional lightning source location data of Lightning Mapping Array (LMA), and referring to Fukui radar echo data and Wajima sounding data, the distributions of charge regions involved in the lightning discharges of three thunderstorms in the Hokuriku region of Japan in the winter of 2014 is investigated. Some interesting conclusions are as follows.

The vertical arrangements of the charge regions involved in the LMA lightning discharges suggest diverse types of charge distribution, including quad-polar, tripole, positive dipole, inverted dipole, and inverted tripole. Riming electrification between graupel and ice crystals was suggested to be the main mechanism responsible for most of investigated thunderstorm cells. The charging between snow/aggregates (which gain positive charge) and ice crystals (which gain negative charge) was supposed to be another mechanism for the inverted charge structure (positively charged region above approximately 0 ℃ and negatively charged region above it) accompanying with weak radar echoes. Meanwhile, the convection crucially affects the diversity of the charge structure by determining the charging mechanisms and where they mainly occur, and by altering the heights of the charge regions (or even making them disappear). Furthermore, a few of lightning discharges appear to occur between the upper positive charge and the overlying negative screening layer. Some thunderstorm cells exhibit main positively charged regions below the middle main negatively charged region and at a lower level that is warmer than approximately −10 ℃. Comparison with cells featuring a typical upper main positively charged region indicates that the cells with lower main positively charged region feature weaker convection indicated by low radar echoes, and therefore the main charging process occurs at around or below −10 ℃ level, a region where graupel gains positive charge by riming electrification.

The negatively and positively charged cores in all investigated thunderstorm cells are distributed between heights of 0.7 and 5.3 km and 1.1 and 4.5 km, respectively. Their corresponding temperature ranges are analogous to those in summer thunderstorms, with negatively charged cores ranging from −1 to −31 ℃ and peaking from −10 to −16 ℃ and positively charged cores ranging from 2 to −26 ℃ and peaking from −7 to −10 ℃. The distance between adjacent charged cores ranges from 0.2 to 3.4 km, yielding mean and median distances of 1.3 and 1.2 km, respectively. Approximately 81% of lightning flashes suggest a distance between 0.5 and 2 km, with the peak of the histogram located at 1–1.5 km.

The duration, horizontal distance and area of the convex hull of the investigated lightning flashes have mean (median) values of 425.0 (297.7) ms, 19.8 (18.3) km, and 176.2 (142.6) km^2, respectively. We estimate the equivalent diameter of the valid charge region for lightning propagation to be approximately 15 km on average if the charge region is circular and has the same area as the mean area of the convex hull of the lightning flash.

The investigated lightning flashes are initiated between 0.8 and 4.1 km, yielding median and mean values of approximately 2.8 km and hitting a peak sample number between 3 and 3.5 km. The corresponding values for the ambient atmospheric temperatures associated with the flash initiations are between 1.6 and −24.9 ℃, −11.9 ℃ (mean), −10.7 ℃ (median) and between −12 and −8 ℃. The flash initiation power

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ranges from −5.6 to 31.4 dBW, yielding mean and median values of both 15.6 dBW, a value larger than that in summer thunderstorms reported in previous study.

Keywords: Winter thunderstorm, Charge structure, Lightning flashes , Flash size, Flash initiation

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