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【論文の内容の要旨】

Lightning is one of the causes of human injuries and casualties, and house and forest fires. It is well known that electronic devices, which are becoming more important in the information-oriented society in recent years, are damaged by lightning strikes. Furthermore, lightning strikes interfere with aircraft operations, including ground services. Progress in lightning prediction is always required to improve the safety of our lives, traffic, and aviation. For more accurate lightning prediction and nowcasting, it is important to clarify the relationship between electrification and microphysical properties in thunderstorms. Although direct observation such as radio-sonde can obtain detailed particle distribution and electric field intensity in a thunderstorm, it is difficult to use it for operational lightning prediction due to the low frequency and limited area of observation. Therefore, it is required to quantitatively evaluate the thunderstorm electrification that causes lightning by applying the latest remote sensing technology.

In this thesis, to reduce the risk of lightning strikes, the relationship between cloud microphysical properties derived from radar observation and lightning activity from lightning location system is investigated, and new lightning indexes that lead to improved lightning forecast and nowcasting using real-time radar remote sensing data are proposed.

Chapter 1 describes briefly the background and objectives. The mechanism of lightning is introduced based on previous studies, and the lightning activity in Japan and the impact of lightning strikes on aircraft operations are described. The current status and issues of lightning prediction are documented, and the purpose of this thesis is described.

Chapter 2 describes two types of radar observation systems, single-polarized and double-polarized radar. The hydrometer classification algorithm using the dual-polarization radar data used is also described.

In Chapter 3, using conventional radars in operation, the relationship between the radar-derived parameters of thunderstorms and lightning activity is investigated. These characteristics, with and without lightning, were observed during a day in 2010 of severe thunderstorms and lightning in Japan and statistically analyzed using radar observations with cell tracking technique. Observed cells were categorized into a cell including cloud-to-ground lightning (CG) and intra-cloud lightning (CGIC cell), a cell containing only intra-cloud lightning (IC cell), and a cell without lightning (NoL cell). These cells were compared to the average and temporal evolution of radar observations. Out of the 265 cells generated, 103 were CGIC cells, 30 were IC cells, and 132 were NoL cells. Significant differences in the average value of the cell categories were detected in the following parameters: lifetime, size, echo top, vertically integrated liquid (VIL), maximum radar reflectivity, and radar reflectivity at the − 10 °C isotherm height. The temporal evolution of CGIC cell characteristics revealed changes in radar reflectivity at 0 °C and − 10 °C that were synchronized with the lightning activity. The VIL value was elevated only for CGIC cells and had the tendency to decrease with time as the lightning activity. CGIC cells produced the highest echo top and maintained their height during their lifetime. To predict CG within 20 min using "35 dBZ radar reflectivity at − 30 °C" as the criterion, a critical success index (CSI) of 0.82 and false alarm rate (FAR) of 0.64 were found to have the best prediction scores.

In Chapter 4, using the dual-polarization Doppler radar with the hydrometeor classification algorithm and lightning location system, radar-derived microphysical properties related to lightning flash rate are investigated, and new lighting indexes are proposed. The ten isolated thunderstorm cases for 2017 and 2018 over the Kanto Plain, Japan, with 351 radar volume scans every 5 min during the summer period are investigated. The ice-related particles within the 35 dBZ volume (V35IC) showed the highest correlation coefficient (r = 0.75) and the lowest normalized root mean square error (NRMSE = 8.3%) in relation to cloud-to-ground lightning (CG), and also best to intra-cloud lightning (IC, r = 0.69, NRMSE = 8.1%). The correlation between V35IC and CG flash rate was better than that of the mixed-phase (between 0 °C and − 40 °C) 35 dBZ volume (r = 0.64), without considering the microphysical particles. The second-best radar-derived microphysical property was the ice mass consisting of the radar grids of all the ice-related particles (r = 0.72). These results suggest that an effective lightning index from the radar-derived properties needs the information of ice-related particle volume adding to the traditionally used hail and graupel volume or radar reflectivity volume. The ice-related particle volume in the colder region of the thunderstorm (air temperature lower than −10 °C) showed a higher correlation with CG and IC than that in the warmer region, especially in IC. These results are consistent with the non-inductive charging theory that has been well accepted for thunderstorm electrification in previous studies. In the time-lag correlation analysis from 0 to −30 min every 5 min before thunderstorm initiation, it was found that the ice-related index of V35IC demonstrated the slowest decrease (r = 0.75–0.65 in 30 min) in the correlation coefficient with time elapse and may be suitable as a lightning nowcast index.

Chapter 5 summarizes the results obtained by this thesis and describes future works. This research reveals the relationship between radar-derived parameters and lightning activity and proposes new lightning indexes to improve lightning nowcast. The usefulness and availability of the proposed indexes are discussed. For more effective usage of these indexes in future operations, it is discussed that the verification of the accuracy of the indexes in various situations is needed.