Introduction

Few studies have been conducted to investigate forecasting techniques for and the climatology of lightning in lake-effect storms. The purpose of our research was to investigate this phenomenon in the lower Great Lakes region. Our first goal was to determine the climatology of lightning in lake-effect snowstorms. In particular, we wanted to determine how often cloud-to-ground lightning occurs in these storms and what time of the year they occur most frequently.

Data and Methods

National Lightning Detection Network (NLDN) cloud-to-ground lightning data were used for our climatology and case study work. Currently, the NLDN only provides cloud-to-ground lightning data for much of the contiguous United States. In future studies, we plan on analyzing total lightning data (cloud-to-ground and intra-cloud) to gain a more complete understanding of electrical properties of lake-effect storms. Early on, we decided to broaden our climatology research to include both lake-effect rain and snowstorms. Limited radar, atmospheric sounding, and lake surface temperature data prior to 1995 led us to focus on the 1995-2005 period for the climate aspect of our research. It was anticipated that the climate aspect of our research would take one to two months to complete. Challenges in locating and processing archived data made this aspect of our research take several months. A few case studies of lightning in lake-effect storms were conducted during the spring 2007 semester.
Dates (00-2359Z) with cloud-to-ground lightning in lake-effect storms were determined through a multiple step elimination process. A computer program sorted through NLDN data files to determine days with cloud-to-ground lightning from 1995 – 2005. Days with cloud-to-ground flashes that occurred from September through March, which we defined as the lake-effect season, remained in the data set. The domain used includes the lower Great Lakes (Lakes Erie, Ontario, eastern Lake Huron and the Georgian Bay) as seen in figure 1. Once dates with cloud-to-ground lightning from September through March were determined, radar imagery from each of these dates were analyzed in order to filter out dates without lake-effect storms. Dates with obvious non-lake-effect features (e.g., thunderstorm squall lines) were eliminated from the data set. Dates with radar imagery which showed banded precipitation originating over the lower Great Lakes remained in the data set. Due to limitations in archived radar imagery (low resolution and missing data), some dates did not have enough data to suggest that there was lake-effect; these dates remained in the data set as well. For each of the dates remaining in the data set, lake surface temperature data from the Great Lakes Environmental Research Lab (GLERL) and sounding data, archived by the University of Wyoming, were examined. Dates that did not have well-aligned flow in the lower levels and a lake surface to 850 hPa temperature difference of approximately 13°C or more were eliminated. This temperature difference is well accepted as an instability threshold for organized lake-effect precipitation to occur (Holroyd 1971). Lastly, graphs of lightning location were created for every date that had not been eliminated. Any date which had lightning more than 50 kilometers away from the Great Lakes was also
eliminated. This was done in order to eliminate any lightning associated with the passage of a cold front, before a lake-effect band formed.

Results and Discussion

It was found that there were an average of 7 days per lake-effect season (September – March) with lightning in lake-effect storms in the eastern Great Lakes. The majority of these days (63.3%) occurred in October and November, however approximately 30% occurred in the December through March period. Moore and Orville (1990) suggested that there are only a few of these storms in a given year; however, Moore and Orville’s study was conducted over a shorter period, 1983-1987.

Improvements in the accuracy of cloud-to-ground lightning detection since 1987, as well as our larger data set could explain this discrepancy. We felt that with a larger data set, more significant results could be obtained. There are an average of 5 storm events per lake-effect season. We defined a storm event as one or more consecutive days with cloud-to-ground lightning in a lake-effect storm. Figure 2 shows the distribution of cloud-to-ground lightning in lake-effect storms in the lower Great Lakes.

Michimoto (1993) conducted research on lightning in convective clouds associated with snowfall in the Hokuriku District of Japan. No lightning flashes were observed by Michimoto when the altitude of the -10°C level was below 1.4 km. We expanded upon Michimoto’s hypothesis to state that the presence of the -10 to -25°C layer within the lake-effect cloud appears to be a good predictor of lightning. This temperature range allows for there to be mixed phases of precipitation (graupel, supercooled water, and ice), which is crucial for electrical charge separation to occur.
BUFFKIT software (developed at the National Weather Service office in Buffalo, NY) can modify model forecast data in order to more accurately depict the lower levels of the atmosphere over the Great Lakes. We have found that this particular feature of BUFFKIT is extremely useful in forecasting lightning in lake-effect storms. BUFFKIT allows us to approximate the temperature and moisture structure of the atmosphere over a lake more accurately than an observed atmospheric sounding that is not located over the lake. Due to the more accurate depiction of lower atmospheric temperature and moisture structure, BUFFKIT software can approximate the lake-induced CAPE (Convective Available Potential Energy), a measure of the instability induced by the lake-air temperature difference. Schultz (1999) concluded that there is little or no CAPE present in lake-effect storms with or without lightning. The 12-13 October 2006 Buffalo, NY lake-effect storm had a maximum forecast lake-induced CAPE value of 2400 Joules per kilogram, a value of CAPE that can be associated with summertime severe thunderstorms. This shows that BUFFKIT software may be more useful than atmospheric soundings when forecasting for lightning in lake-effect storms.

Dissemination of Work

Our research was presented at several venues, which gave us the opportunity to get feedback from many scientists. Early work was discussed at the Lake-effect Conference in mid-October 2006 on the SUNY Oswego campus. Funding from the SCAC grant allowed Jason Keeler to discuss the research with forecasters at the National Weather Service office in Buffalo, NY in mid-November 2006. A poster presentation was given at the Sigma Xi Poster Session on campus later in November. Work was presented to meteorology faculty and students in an independent study seminar in
December 2006. Two posters were presented by Dr. Steiger and Jason Keeler at the American Meteorological Society (AMS) annual meeting in San Antonio, TX in January 2007. The AMS annual meeting had over 3000 attendees, so there were plenty of opportunities to discuss our work with experts in both lightning and in lake-effect storms. A presentation on forecasting lightning in lake-effect storms was given by Jason Keeler at the Northeastern Storm Conference in Springfield, MA and at Quest. We have collaborated with Bob Hamilton of the National Weather Service office in Buffalo, NY on some of this research. Dr. Steiger, Jason Keeler and Mr. Hamilton are in the process of editing a manuscript which we will submit to the Monthly Weather Review, a peer-reviewed journal of the AMS.

The remainder of our funds will be used to cover publication fees from the Monthly Weather Review and to purchase a copy of the book The Electrical Nature of Storms for $104.75. We had planned on purchasing this book earlier; however, the publisher did not have it available for purchase until recently. Publication fees not covered by the remainder of the SCAC grant will be covered by the National Weather Service.

Acknowledgements

Thank you to Bob Hamilton of the National Weather Service office in Buffalo, NY for his collaboration on this research. Vaisala, Inc. generously provided the cloud-to-ground lightning data at no fee. The Student/Faculty Collaborative Challenge Grant provided funding for this research and we thank the SUNY Oswego Scholarly and Creative Activity Committee.
References


Figures

Figure 1. Domain used for sorting through NLDN data to determine dates with CG lightning (shown by black box) in the lower Great Lakes. Included in the domain are Lakes Erie, Ontario, a portion of Lake Huron and the Georgian Bay.
Fig. 2. Cloud-to-ground flash density (flashes km\(^{-2}\) yr\(^{-1}\)) in the lower Great Lakes for lake-effect storms during the 1995-2005 period.