LAKE-EFFECT STORM CLIMATOLOGY STUDY

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Lake-effect weather can affect millions of lives in upstate New York every winter. A major field project aimed at studying lake-effect weather is currently in the planning stages. In order to assist the planning and coordination of this project a climatology study of lake-effect weather is underway. The two main aspects of this study are focused on 1) snow band climatology and 2) lake-effect lightning climatology. In both cases there was little differences between Lake Erie and Lake Ontario with respect to total events, however there was a much more significant difference when the lakes were compared on a monthly scale.

I. Introduction

Lake-effect snow can severely impact residents near the lower Great Lakes (Erie and Ontario). Lake-effect storms are relatively well-forecasted; however there are still significant errors with respect to predicted band location and snowfall rates (Ballentine, 2007). More research is needed to fully understand the dynamics and behavior of this phenomenon. The goal of this project is to determine the climatology of lake-effect events in order to support the planning of a major scientific field project aimed at studying lake-effect weather produced by the lower Great Lakes. This is a two part project. Part I of the project will focus on the type of lake-effect snow being produced, specifically the difference in occurrence between wind parallel and shore parallel bands off of both Lakes Ontario and Erie. The second part of the project will examine lightning associated with lake-effect weather events off of the lower Great Lakes.

II. Lake-effect Band Frequency

The first part of this project will answer two questions about lake-effect snow occurrence per lake: 1) how often per year do they occur? 2) which band type can be expected more often; wind parallel bands or shore parallel bands.

a. Data and methods

Lake-effect events for both Lake Ontario and Lake Erie were observed from 1996 to 2001 between October and March. Those months were chosen because the majority of lake-effect events tend to occur during the cool season.

For this time period, both radar and upper-air soundings were examined in order to search for lake-effect characteristics. They had to be used in conjunction with each other to act as mutual fail-safes since the radar data used did not have very high spatial or temporal resolution, so reflectivity could have been misinterpreted undermining the credibility of this research. For example, there could be reflectivity over a lake which does not necessarily look like lake-effect snow band and could be associated with a low pressure system, but in reality it is a lake-effect snow event because the upper air soundings show the conditions were right for a lake-effect storm to form. Also, upper-air sounding data were only observed at 00Z and 12Z (7 pm & 7 am) where as radar data were available hourly most times throughout the day. So using upper-air soundings might have hinted a lake-effect band could form, but the radar data can be used as visual confirmation it did actually form.

Some radar data were easy to confirm lake-effect simply by whether or not there was reflectivity over the lake during the day. If there was no reflectivity over either lake, then the day was diagnosed as having no lake-effect. However, if there was reflectivity over the lake then the upper-air sounding data were analyzed in order to confirm the atmosphere met the conditions for lake-effect to occur. Since the radar data was only available every 4 hours, satellite data or higher resolution radar data would give a better idea whether or not lake effect occurred during those gaps, but this would only be used if certain days were questionable. These are the parameters that were examined to determine whether or not the atmosphere was conducive to lake-effect:

i. T(lake)-T(850) $\geq$ 13°C, where T = temperature

ii. No to weak low-level vertical wind shear (<30°), between the surface and 700mb

iii. No or weak low level capping inversion, capping inversion base above 800mb.

Once a band was confirmed as having existed, the band was classified as either a wind parallel band (Fig. 1) or shore parallel band (Fig. 2). Niziol et al. (1995) defined both of these band types. A wind parallel band is a band which forms parallel to the low-level wind direction and also one which forms parallel to the short axis of the lake. A shore parallel band is a band which forms parallel to the long axis of the lake. This band will form with a west wind over Lake Ontario and with a southwest wind over Lake Erie.

Using an EXCEL spreadsheet, a binary scale (0/1) was used placing a one where the band type occurred and over which lake also placing a zero if it did not. Then these values were added up obtaining a total for each band type over each month.

b. Results

Table 1 shows the results from analyzing every day from 1996 to 2001 of the months of October through March. The main months for lake effect bands are December and January for both lakes an average of about five events occurred per month per lake.

A difference between the two lakes is Lake Erie tends to have more events in October than Lake Ontario, but Ontario generally has more events toward the end of the lake-effect season in February and March when Lake Erie tends to freeze over. Another interesting note is the preponderance of shore parallel bands compared to wind parallel

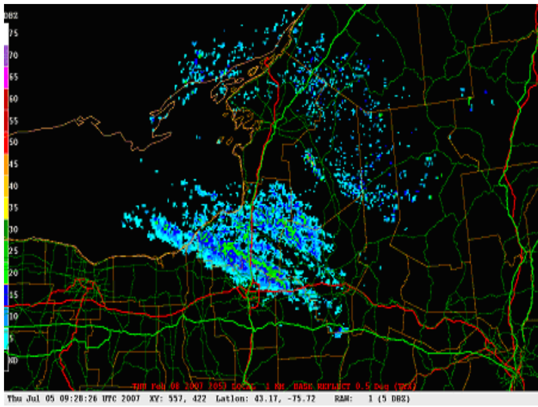

Fig. 1: Radar image of a wind parallel lake-effect

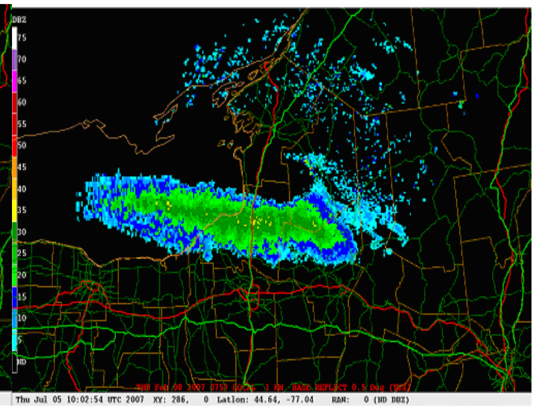

Fig. 2: Radar image of a shore parallel lake-effect band.

Table 1. Average of the number of lake effect bands per month.

Average	**Erie**		**Ontario**	
Month	*Shore-Parallel*	*Wind Parallel*	*Shore-Parallel*	*Wind Parallel*
October	1.6	0.2	0.8	0.4
November	1.8	1.6	1.8	1.8
December	4.4	1	4.6	0.8
January	4.6	0.4	4.4	1
February	1.2	0.4	1	1
March	1	1.2	2	1
Total	14.6	4.8	14.6	6

bands. Shore parallel bands double to triple wind parallel bands in occurrence. Both lakes have the same number of shore parallel events each season (14.6).

III. Lightning Study

The second facet of the lake-effect project deals with the electrical aspects of lake-effect storms. This research is focused on comparing lighting events between Lakes Erie and Ontario. This research is divided into three main sections. The first section compares the frequency of lightning events between Lakes Erie and Ontario. The second step in this research categorizes the lightning events by precipitation type, e.g., rain, snow or mix. The third and final step in this research compares the intensity (number of flashes per storm) of lightning events by lake.

a. Data and methods

There is a particular methodology that was employed during all three parts of this research. All three parts centered on looking at lake-effect lightning events. Materials consisted of a list of lake-effect lightning events between 1996-2007 found by Hamilton et al. (2008), National Lightning Detection Network (NLDN) lightning density plots (e.g.,(Fig. 3) for those events, National Environmental Satellite, Data, and Information Services (NESDIS) radar data, National Severe Storms Laboratory (NSSL) archived surface observations, and upper air sounding data archived by the University of Wyoming.

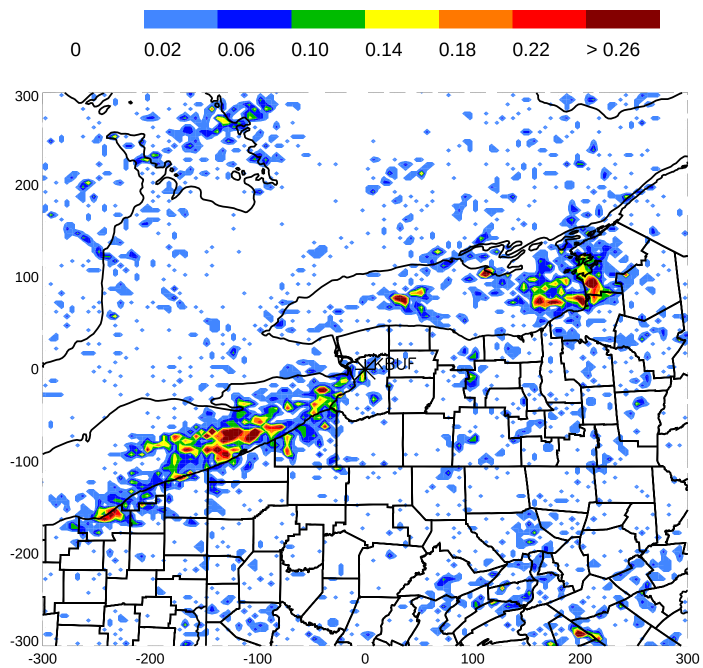

Fig. 3: Composite lightning density for all of the lake-effect events found by Hamilton et al. (2008).

The first section of research, comparing lightning event frequency by lake, centers on the NLDN lightning density plots. The first step in the diagnosing of lake-effect lightning is analyze a lightning density plot for a given lightning event. In some cases this is enough to determine which lake produced the lightning.

However there is often a lot of noise on some of the density plots, and it is hard to determine which lake produced lightning. If that was the case, radar data were examined for the given date, and looped in order to find lake-effect precipitation. However this was sometimes inadequate due to the low resolution of radar data, or lost data. In that case, sounding data (typically from measurements at the NWS at Buffalo) were examined; the main parameter examined on a sounding was the wind direction in the lower levels of the atmosphere.

b. Results

It was found that both lakes, Erie and Ontario produced a very similar frequency of lightning (Fig. 4). In the 12 year data set of lake-effect lightning events provided by Hamilton et al. (2008) 60 of them were attributed to Lake Ontario and 58 were classified as Lake Erie events.

While the lakes had a similar frequency of lightning events, there were major differences between the two lakes with respect to time of year (Fig. 5). It was found that in the late fall and early winter (October & November) both lakes peaked in frequency of lightning events, which agrees with research done in the past (Niziol et al. 1995).

However, in the early lake-effect season (September through early December) Lake Erie dominated as the main producer of lake-effect lightning events, while in the core of winter in January and February, Lake Ontario produced a significantly higher amount of lightning than Lake Erie.

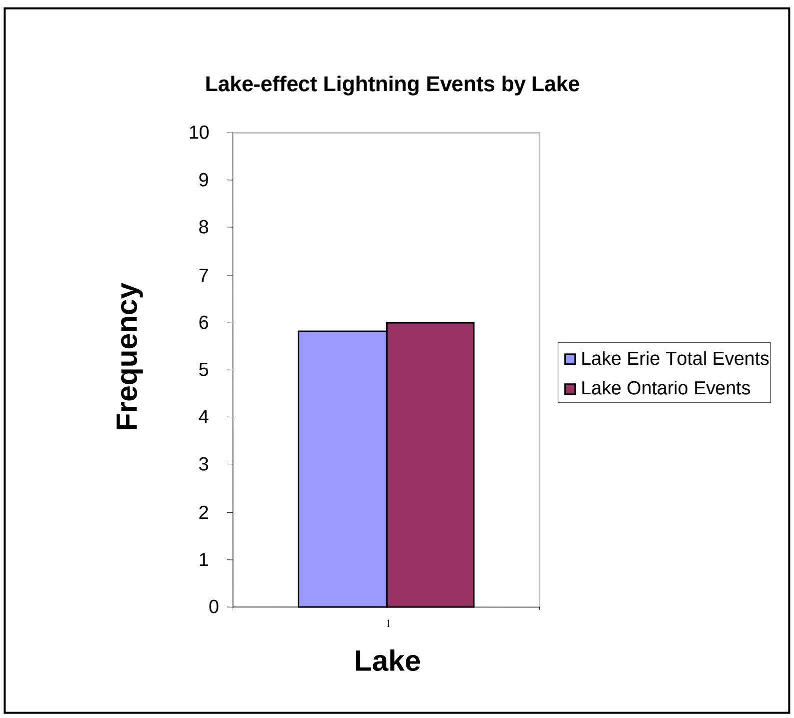

Fig. 4: Frequency of lake-effect lightning events per lake (1995-2007).

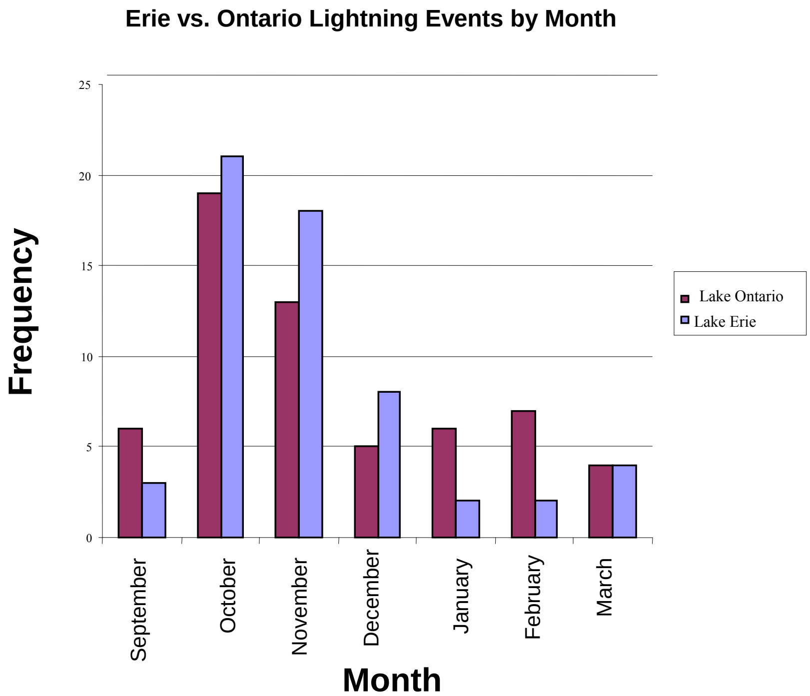

Fig. 5: Lake-effect lightning events compared by month (1995-2007).

c. Discussion

From the results several conclusions can be drawn about the climatology of lake-effect lightning for each individual lake. In the early part of the season lake-effect lightning is more apt to be found off of Lake Erie. This is most likely due to the fact that Lake Erie has a much smaller volume (484 km^3) than Lake Ontario (1640 km^3) (EPA, 2006). From this the inference can be made that Lake Erie's water temperature will fluctuate more through the seasons than Lake Ontario. Hence, in the early lake-effect season Lake Erie will be significantly warmer than Lake Ontario and therefore more likely to produce lake-effect thunderstorms. Subsequently Erie will cool down at a more rapid rate than Ontario throughout the winter and will be colder than Ontario in the latter part of the season.

This shows very good support for the accepted hypothesis that lake-induced instability is directly correlated with the strength of convective updrafts and lake-effect weather. This is because if there is a warmer lake, than there is a higher potential for greater amounts of lake-induced instability and more lightning.

IV. Future Research

The second phase of this project is to determine the precipitation type of lake-effect lightning events, and compare this characteristic for the two lower Great Lakes. This involved a little bit more methodology and is somewhat more subjective. Precipitation type of lake-effect can be difficult and relies on several different parameters.

To categorize precipitation type for this project, three categories (rain, snow, mix) were established and a funnel approach was utilized to make the data more manageable. First the month of the event was investigated: if the month was January or later it was classified as snow. The reasoning for doing this is that the average lake temperatures for Ontario and Erie at this time of year are around 5°C or less. Since lake-effect storms require at least a 13°C difference between the surface lake temperature and the 850mb level, this incurs that the 850mb temperature must be at least -8°C. In the winter months this will almost always yield a below freezing temperature near the surface, and thus all lake-effect precipitation from January through until the end of lake-effect season will be classified as snow.

The next step in this funnel approach is to examine an upper air sounding from the date (typically taken at 12Z from Buffalo, NY). The temperature at 850 mb is examined and if this temperature is above 0°C then the event is classified as rain.

The next step is to examine surface data for every event. This is done in order to get an idea of the temperatures at the surface around the region, or in the lake-effect precipitation itself. However mixed precipitation can be found even if the temperatures are into the lower to mid 40s °F.

The final step in this methodology is to reexamine at the upper air sounding, and perform a "modified" top down method. A top down method used in diagnosing lake-effect precipitation is very similar to the top down method used to diagnose precipitation types in larger synoptic scale storms (Vasquez, 2002) except for one major difference. In larger scale storms the atmosphere is examined from high up in the atmosphere, where in lake-effect events only the lower section (700mb and lower) of the atmosphere will be analyzed as lake-effect clouds only extend about 3km AGL.

The top down method is fairly simple conceptually. It follows the path of a precipitation particle from start to finish (high to low altitude) and traces its track along the vertical axis of the atmosphere. Layers of above freezing air are typically examined the most thoroughly. If a precipitation particle falls though a significantly thick layer of above freezing air (> 600ft), it will at least partially melt. Rules of thumb have been developed by meteorologists (Vasquez, 2002) to determine how thick of a layer is needed to fully, or partially melt a frozen particle falling through the cloud. By using these accepted rules of thumb the top down method is generally accurate and efficient. The precipitation type of a lake-effect event can typically be accurately estimated by using this methodology.

For the lake effect occurrence study, data from 2002 to present still need to be analyzed in order to confirm the trend developed and explained earlier. After all these years are analyzed, there can be high confidence in the results. Also, satellite data and higher resolution radar data will be obtained for the questionable (unclassifiable) days and a consensus formed on whether or not lake-effect did occur.

The results for the precipitation type classification study are not listed because the data has not yet been fully analyzed. There are some indications that Lake Erie produces more rain and mix events where as Lake Ontario produces more snow events, however this cannot be concluded because there is still a large portion of data to go though.

In the future the precipitation type classification will be completed, and the third aspect of this research project can begin. Again the third and final step in the lake-effect lightning research will be to classify lightning intensity (number of flashes) of each lightning event, and compare Lakes Erie and Ontario by lightning intensity in order to determine which lake produces the strongest storms.

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