

# Final Report

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Partners or Cooperative Project: [Partners Project](#)

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## SECTION 1: PROJECT OBJECTIVES AND ACCOMPLISHMENTS

The overall objectives of this project were to 1) determine the influence of the Lake Erie lake breeze on locations of thunderstorm initiation and evolution, 2) determine atmospheric conditions most favorable for thunderstorm initiation associated with the lake breeze, and 3) determine the influence of other boundary layer convergence zones on thunderstorm initiation near the lake breeze. To reach these goals, it was necessary to conduct analysis of numerous cases of thunderstorm initiation near the lake breeze using Cleveland, OH, WSR-88D data, surface observations, and other data sources.

Thunderstorm evolution was examined primarily through analysis of data collected by the WSR-88D in Cleveland, OH. Given the large amount of time required to analyze these data, it was decided to determine which dates were most likely to have both thunderstorms and a lake breeze. In order to accomplish this, we examined each date during April-September, 1999-2000 in the following ways: (1) Determined dates with thunder or moderate precipitation at stations TOL, CLE, ERI, MFD, CAK, or YNG, (2) Added dates during which moderate precipitation ( $> 0.25$  inches) was reported at any of 24 Co-op observation sites in the Cleveland NWSFO warning area (about 1 coop site in each county), and (3) Removed all dates when a lake breeze was unlikely. Dates with a significant synoptic system (low pressure system or front, for example) or with surface wind speeds over 15 kt were removed.

This analysis resulted in 81 possible study cases in 1999 and 85 possible study cases in 2000. WSR-88D data were requested and, if available, analyzed for all 166 dates. Of these days, approximately 25% had missing or inadequate radar data for the hours of interest.

Summary statistics for 1999/2000 cases:

Total number of cases examined: 166

Percent of days with surface reports of precipitation: 45%

Percent of dates with surface reports of lake breezes: 20%

Number of dates with thunderstorms near the lake breeze, and adequate radar data: 6

Figure 1 shows radar images from two cases we studied. In the 19 April 1999 case, thunderstorms within 10 km of the lake breeze were much more intense than those developing further from the front. In the 11 June 1999 case, just the opposite occurred. Thunderstorms more than 10 km from the lake breeze front were, on average, more intense. Of the six days examined in detail, three exhibited more intense thunderstorms near the lake breeze front, two featured weaker thunderstorms near the lake breeze front, and one featured little difference between storms near and far from the lake breeze front.

Environmental conditions on each of the six days with thunderstorms present near the lake breeze were examined in order to gain insight into mechanisms that may be responsible for their development. Summary data on storms near and far from the front and environmental conditions on these days are given in the preprint article below.

Observed environmental conditions were consistent with two processes cited in past scientific literature on thunderstorm development near density currents (i.e., lake breezes in the current study). Thunderstorms tended to be more intense near the lake-breeze front when the low-level wind shear was oriented opposite (toward the south) that induced by the southward-moving lake breeze front (toward the north). A previous COMET training project (Comet 1996 in the attached preprint) indicated that when the ambient shear was opposite that induced by the density current, then horizontal vorticity patterns would favor storm development near the front. If this mechanism is responsible for the observed thunderstorm intensities, then it has interesting implications for lake-breeze thunderstorm forecasting and frequency of occurrence.

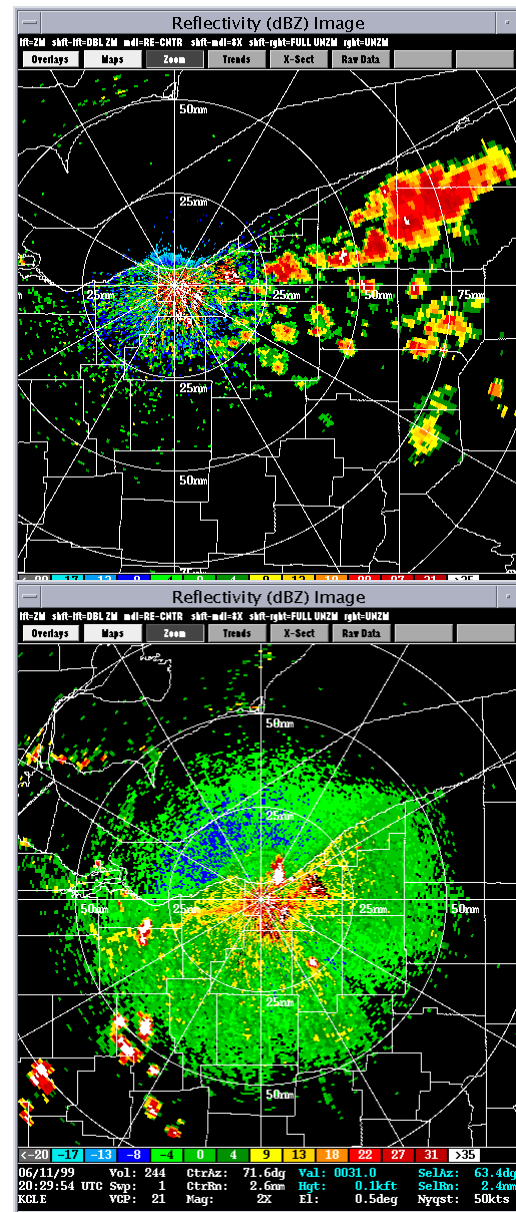


Figure 1. WSR-88D observations of reflectivity on 19 April 1999 (top) and 11 June 1999 (bottom)

We also found that thunderstorms tended to be more intense when their direction of movement was nearly parallel to the orientation of the lake-breeze front (approximately west-east). Days when storm movement was at large angles to the lake breeze front exhibited weaker storms near the front.

This study gives intriguing results that have forecasting implications. The observations suggest that low-level wind shear direction and storm movement should be considered in developing forecasts of thunderstorm development and intensity in the vicinity of lake-breeze fronts. However, a larger project will be necessary to fully understand the possible role of these mechanisms for storm development near lake breeze fronts. Please see the attached preprint article for more details on our research methods and findings.

## SECTION 2: SUMMARY OF UNIVERSITY/NWS/DOT EXCHANGES

Communicating our research results to operational forecasters and research scientists was an important goal of this work. Findings from our analysis of 1999/2000 cases were presented at the 2002 Great Lakes Operational Workshop in Traverse City, MI, 2003 Great Lakes Operational Workshop in London, Ontario, and at the American Meteorological Society Midwestern Extreme and Hazardous Weather Conference in Champaign, IL. A copy of the preprint article from the latter conference is attached below and will be placed on the internet through the Cleveland WFO office.

In order to further facilitate the usefulness of our research findings, researchers from the University of Illinois and WFO CLE met in Cleveland, OH, to discuss findings with forecast staff. WFO forecasters and staff were invited to a presentation on the goals and findings of this study on the morning of 26 September. An extended discussion followed, which emphasized personal experiences of the forecast staff and discussion of which environmental factors may be most useful to examine in predicting lake-breeze thunderstorms.

## SECTION 3. PRESENTATIONS AND PUBLICATIONS

LaPlante, R., and D. Kristovich, 2002: The Influence of the Lake Erie lake breeze on thunderstorm initiation. Great Lakes Operational Workshop, Traverse City, MI.

LaPlante, R., and D. Kristovich, 2003: Are Thunderstorms that form along Lake Breezes More Intense? Great Lakes Operational Workshop, London, ON, Canada.

LaPlante, R. and D. Kristovich, 2003: Are Thunderstorms that form along Lake Breezes More Intense? Workshop, WFO Cleveland, OH.

Kristovich, D.A.R., R. LaPlante, N.F. Laird, W.T. Kubina, 2003: Are Thunderstorms That Form Along Lake Breezes More Intense? Midwest Severe and Hazardous Weather Conf., Central Illinois AMS.

## SECTION 4. SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED

### 4.1 *Academic Partners*

This grant from COMET has increased our awareness of forecasting problems, which will likely help us define future research efforts to be beneficial to the operational community. It has also increased our access to operational datasets, particularly from WSR-88D, which will be beneficial in ultimately better understanding coastal atmospheric processes in the Great Lakes area.

University staff time outside of the funded COMET project was used for initial determination of appropriate dates for which WSR-88D data should be ordered. This determination included analyses of surface precipitation observations, satellite imagery, and surface analyses (see Section 1).

Initial delays in obtaining WSR-88D data slowed initial progress. No other problems were encountered.

### 4.2 *Forecaster Partners*

This grant from COMET has afforded WFO CLE the opportunity to develop ties with the research community and reinvigorate local research efforts. This research collaboration will help the operational staff increase their understanding of convective development near the lake breeze. This increased knowledge about the initiation of convection will increase the situational awareness of the operational staff. With the successful completion of this study, perhaps a more comprehensive study on convection near the Great Lakes can be pursued.

In order to facilitate the usefulness of this project, researchers from the University of Illinois and WFO CLE met in Cleveland, OH, to discuss findings with forecast staff. This offered a particularly useful opportunity to discuss findings and gain insight from operations staff.

{Copy of reprint to the 2003 Midwest Regional Conference on Extreme and Hazardous Weather}  
**Are Thunderstorms That Form Along Lake Breezes More Intense?**

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## 1. BACKGROUND

Lake breezes are common aspects of summertime weather in the Great Lakes region. In addition to providing cool breezes from the nearby lake, forecasters' experience indicates that the lake breezes have important impacts on the intensity, location, and timing of afternoon thunderstorms. In particular, lake breeze fronts (the front edge of the lake-cooled air moving inland) can be the location of new, intense afternoon thunderstorm activity. Since large cities and airports are often located within a few 10s of km from the shores of the Great Lakes, lake breeze thunderstorms pose significant difficulties for regional forecasters.

The presence of the lakes have been observed to have various impacts on thunderstorm development and evolution. For example, numerous studies have been conducted indicating thunderstorm development near the lake breeze front (e.g., King et al. 2003). Other studies have shown that cool stable air from over and near the lakes can decrease the intensity of storms. Interestingly, recent climatological studies show decreases in thunderstorm activity and summer precipitation over and near the lakes, but little or no increase in precipitation further from the lake shores (e.g., Scott and Huff 1995).

The goal of this exploratory study is to provide forecasters with information on the role of the Lake Erie lake breeze on thunderstorm initiation and evolution. Using observations in the Cleveland, OH, NOAA National Weather Service Office Cleveland (CLE) County Warning and Forecast Area (CWFA) forecast area, the development and movement of the lake breeze front, location of thunderstorm development, and ultimate storm intensity were documented for two summers.

## 2. METHODOLOGY

Level II data from the KCLE WSR-88D site, taken during the summers of 1999 and 2000, were primarily used to determine characteristics of the lake breeze front and thunderstorms in the Cleveland area. These radar data were retrieved for all dates when surface observations of precipitation were observed

within the WFO Cleveland CWFA. In total, radar data archives from 166 days for 1999 and 2000 were examined.

High-reflectivity "thin lines" on radar imagery as has been shown by numerous studies to closely coincide with the location of lake- or sea-breeze fronts in coastal regions. In the northern Ohio region, these thin lines typically were first observed within 4 km of the south shore of Lake Erie usually between 1100 and 1500 LST and moved southward at varying speeds.

In order to determine the influence of lake breezes on the development and evolution of convection, radar data from all dates with lake breeze front thin lines were examined for the development of convection both near and far from the lake breeze front. For purposes of this study, a convective storm was defined as an isolated area of reflectivity over 20 dBZ, which was present for at least 3 radar volume scans. Up to 15 isolated storms were identified for each date. Each storm was classified as either being along the lake breeze front, within 10 km ahead or behind the front, or more than 10 km from the frontal location. For each storm identified, initiation and dissipation times, maximum reflectivity achieved in the storm, and volume integrated liquid (VIL) were recorded. Due to problems with data availability, VIL was often not available, so was not used for the current study.

Dates with an observed lake breeze front thin line, thunderstorms forming both near and far from the front, and adequate radar data, are given in Table 1. In total, only six dates were found to be appropriate for this study, far fewer than anticipated (amounting to approximately 5% of the days with adequate radar data). Climatic variability likely plays a role in this low frequency. A possible physical explanation for the low frequency of these events is discussed below.

## 3. RESULTS

Some characteristics of storms that developed near and far from the lake breeze on each of the six dates of study are listed in Table 1. For simplicity, only differences between storms forming within 10 km of the lake breeze front and those that developed further away are given.

Of the six dates examined, thunderstorms were stronger near the lake breeze front than far from the

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front half of the days (19 April 1999, 7 June 1999, 9 September 2000). On two of the cases studied, thunderstorms near the front were weaker (11 June 1999 and 5 May 2000). One date showed little difference in intensity between storms near and far from the front (28 August 1999). Figure 1 shows example reflectivity patterns for two cases; one with stronger storms near the front and another with stronger storms far from the front. While there were often large differences in times that storms developed near and far from the lake breeze front, there was no correlation between relative strength of the storms and the differences in times that they developed. The remainder of this study will focus on storm intensity.

Previous studies have examined the mechanisms that may cause storms near lake-breeze or similar fronts to be stronger, or weaker, than their environments (discussed in COMET 1996). In general, the mechanisms tend to relate to movement of the storms, overall atmospheric stability, and low-level shear profiles. A wide range of parameters related to environmental stability, low-level winds and wind shear, and storm movement were examined. A few of these parameters are given in Table 1.

No correlation was found between most of the parameters examined. In particular, measures of atmospheric stability (such as CAPE, lifted index, etc.) were not obviously related to the relative strength of the storms close to the lake breeze front. Factors related to storm movement and low-level shear showed some correspondence. Figure 2 illustrates the relationship between storm motion and relative storm intensities. It was found that on days when storms propagated within about 30-40° of the orientation of the lake breeze front (west-to-east), those close to the front tended to be stronger. On days when storms moved in a direction more perpendicular to the front, storms close to the front tended to be weaker. This relationship is similar to that postulated in a modeling study by Mann (2002).

COMET (1996) argued that low-level wind shear relative to a front would play an important role in the intensity of storms. In particular, if the environmental wind shear was oriented in the same way as the shear behind the front, then storms would tend to be weak. If the environmental wind shear was oriented in the opposite direction, then the storms would tend to be strong. Since the lake breeze on the south end of Lake Erie would result in low-level wind shear directed toward the north, then it would be expected that cases with low-level environmental shear having a similar southward component would result in stronger storms near the front.

Figure 3 examines this hypothesis for the Lake Erie lake breeze cases studied here. In the two cases with northerly wind shear, storms were weaker near the lake breeze front than far from the front. On the three dates with stronger storms near the front, the

low-level shear was directed in a southerly direction. This is qualitatively consistent with the hypothesis described in COMET (1996).

#### 4. IMPLICATIONS

This exploratory study seeks to utilize an observational approach to understand the influence of the lake breeze front on thunderstorm development and evolution near the WFO Cleveland CWFA. It is shown that thunderstorms near the lake breeze front can be relatively stronger or weaker, depending on environmental conditions. While it is impossible to determine the most important factor with the limited number of cases available for study, storm evolution appears to be related to dynamic characteristics of storm movement and environmental shear, rather than stability-related factors.

Two mechanisms for storm intensification or weakening near the lake breeze front were consistent with the results of this study. Mann (2002) suggested, based on numerical modeling experiments, that storms were best able to strengthen in the vicinity of a lake breeze when they are moving nearly parallel to the orientation of the front. This type of movement would result in the storms remaining in the convergence region ahead of the front for long time periods. In this study, there was a weak tendency for storms to be most intense when their movement was within 30-40° of the west-to-east frontal orientation.

COMET (1996) emphasized the role of wind shear impacts on storm evolution in the vicinity of a density current, similar to lake breeze fronts. If the low-level wind shear was opposite the shear induced by the lake breeze circulation, then updrafts would remain nearly vertical and storms would be strengthened by the resulting horizontal vorticity field. Weaker storms would result near the front if the environmental shear was oriented in the same direction as the front-induced shear, inhibiting storm development. In our case, lake breeze circulations would induce a northward-oriented shear profile, from southward lake-breeze flow near the surface to northward return flow air at higher altitudes. On dates when the environmental shear had a northward component, storms were weakened near the front, as predicted.

It should be noted that the days when storms were strongest near the front (19 April 1999 and 9 September 2000) had favorable conditions for both storm movement and low-level shear. It is entirely possible that dates where both criteria occur will produce the greatest difference in storm intensities. Given the relative infrequency with which these types of events occur in this region, a numerical modeling study would be useful for providing insight into the relative importance of these processes. Forecasters in WSO CLE will have the opportunity to keep note of

shear and storm movement in upcoming summers to verify whether the proposed mechanisms are valid.

It is interesting to note that the shear mechanism described in COMET (1996), if important in these cases, would have implications for the frequency with which strong lake breeze thunderstorms occur. Since nearly all of the cases studied here had winds from a westerly component (with the exception of 11 June 1999), favorable conditions for strong thunderstorms would imply a veering wind profile and northerly wind components at higher levels. In this region, however, these conditions usually result in a drier air mass not conducive for thunderstorms. It is possible that this is one reason that lake breeze thunderstorms were infrequent in this study area. This implies that strong lake breeze thunderstorms would be more likely north of the lake, where southerly large-scale flow would be present in favorable shear conditions.

**Acknowledgements:** The authors appreciate the efforts of Maria Peters in learning how to use the WATADS software package for examination of radar data, teaching it to the UIUC research group, and for help in analyzing surface and radar observations. This paper is funded under a cooperative agreement between the National Oceanic and Atmospheric Administration (NOAA) and the University Corporation for Atmospheric Research (UCAR) under the Cooperative Program for Operational Meteorology, Education and Training (COMET) program (COM UCAR S02-32802). Any opinions, findings, and

conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the COMET program, NOAA, its sub-agencies, UCAR, or the Illinois State Water Survey.

## 7. REFERENCES

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Table 1. Summary of some differences in characteristics of thunderstorms observed near the lake breeze front (LBF) and those observed far from the lake breeze front. Storm motion, average winds, and shear characteristics were derived from sounding data.

Date	Difference * (near-far from LBF)		Estimated Storm Motion		Average Wind, Sfc-6km		500-2000m Shear	
	Reflectivity (dBZ)	Initiation time (mins)	(Deg)	(Kts)	(Deg)	(Kts)	Northerly Component (Kts)	Easterly Component (Kts)
19 Apr 1999	10.5	-82	308	20	278	27	1.1	-6.0
7 Jun 1999	5.0	46	296	18	266	24	6.5	-1.7
11 Jun 1999	-2.0	18	188	9	158	12	-1.8	-1.8
28 Aug 1999	0	102	316	13	286	18	5.8	3.0
5 May 2000	-3.0	177	302	12	272	17	-1.3	-2.8
9 Sep 2000	18.5	-159	281	6	251	8	3.2	-3.8

\* Near lake breeze front includes storms which initiated within 10 km and far from lake breeze front include storms initiating more than 10 km from the front.

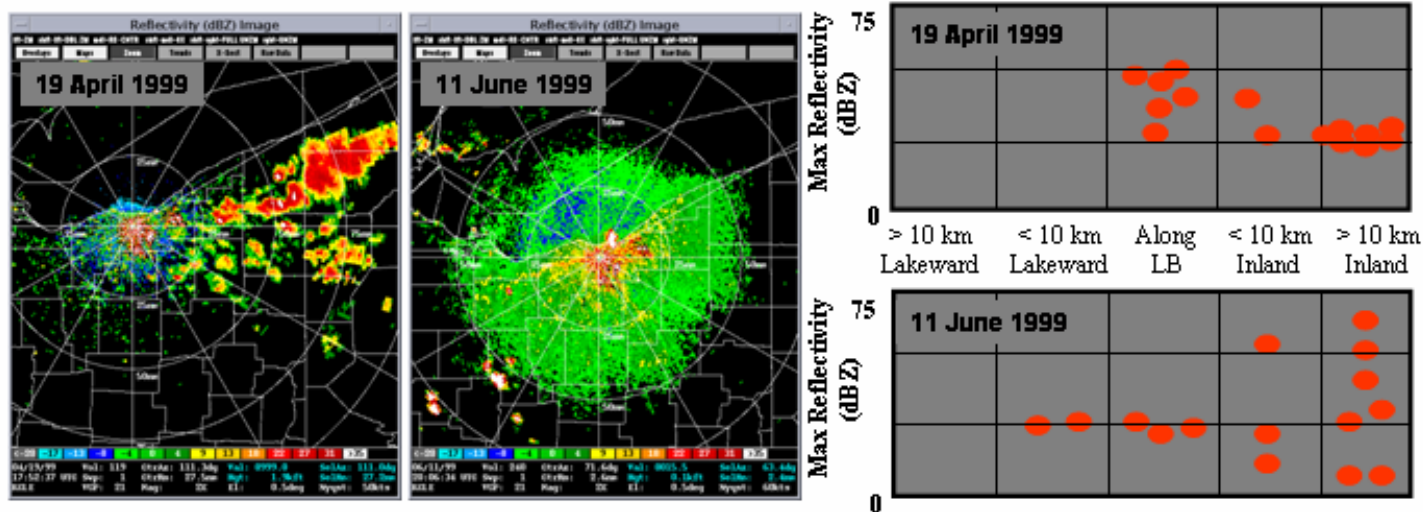


Figure 1. Radar reflectivity field observed by the WSR-88D site in Cleveland, OH, on 19 April (left-most) and 11 June 1999 (center). Right panels show maximum reflectivity values for storms (red dots) observed on 19 April 1999 (top-right) and 11 June 1999 (bottom-right) as functions of distance from the lake breeze front (LB).



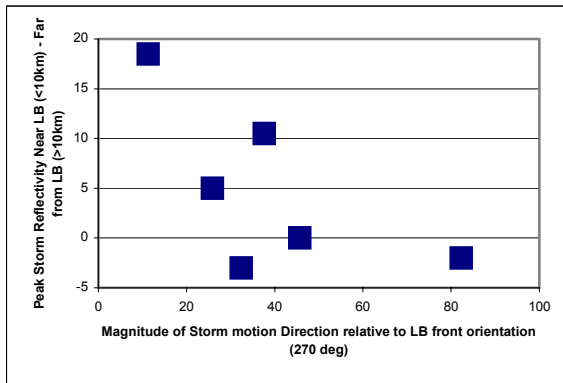


Figure 2. Radar reflectivity difference between storms close to the lake breeze and those more than 10 km away as functions of storm motion direction. Storm motion is given as magnitude of the difference from the lake breeze frontal orientation (west-to-east).

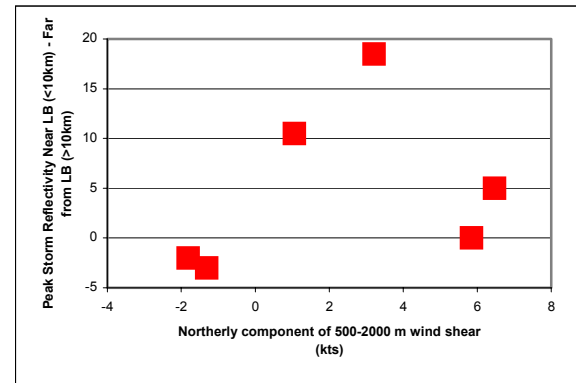


Figure 3. Plot of radar reflectivity difference between storms close to the lake breeze and those more than 10 km away as functions of north component of wind shear. Wind shear was calculated from 500 m to 2000 m height. Positive shear components imply a southward-component.