P12.7 ELBOW 2001 – STUDYING THE RELATIONSHIP BETWEEN LAKE BREEZES AND SEVERE WEATHER: PROJECT OVERVIEW AND PRELIMINARY RESULTS

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1. INTRODUCTION

The Meteorological Service of Canada (MSC), York University, University of Western Ontario (UWO), and University of Guelph - Ridgetown College conducted a field experiment during the summer of 2001 as part of the ELBOW 2001 - Effects of Lake Breezes On Weather project. The study area is located in southwestern Ontario, a generally flat and mainly agricultural district within the Great Lakes region of North America (Figure 1). The project objectives are to:

- improve our understanding of lake breeze circulations, including the interactions of lake breeze fronts with fronts from adjacent lakes and other mesoscale boundaries,
- improve our understanding of the initiation and enhancement of thunderstorms at lake breeze fronts and related severe weather, and
- evaluate and improve current methods of detection and short-range forecasting of lake breeze fronts and related severe weather, including the use of high-resolution numerical models.

The anticipated benefits of the study include concepts, tools and algorithms to help severe weather forecasters assess the threat associated with lake breeze-related storms. This will hopefully result in more accurate and precise watches and warnings with longer lead times. Improvements to high-resolution models used for convective forecasting are also anticipated.

2. BACKGROUND

Lake breeze circulations, like sea breeze circulations, are driven by horizontal pressure gradients resulting from daytime differences in temperature between cool air over water and warm air over land. Where present, the circulations control the meteorology through the lowest layers of the atmosphere. The cool marine air associated with lake breezes generally acts to suppress convective activity over water and at inland locations immediately downwind. However, the leading edge of the lake breeze circulation, called the 'lake breeze front', is a zone of enhanced moisture, lift, shear and vorticity that can act to trigger the development of thunderstorms in a convectively unstable environment. This is especially true when lake breeze fronts interact with thunderstorm gust fronts, synoptic-scale fronts, or other lake breeze fronts. The arrival of the lake breeze front is frequently associated with a rapid decrease in temperature, a rapid increase in relative humidity, and a shift to onshore winds. However, the arrival signature in the temperature and relative humidity data typically becomes more subtle with increasing inland distance due to the rapid modification of the marine air mass over land.

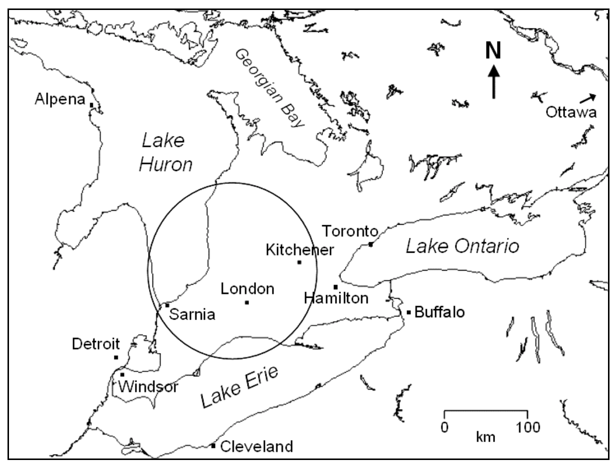

Figure 1. Map of southern Ontario giving the names of lakes and nearby urban centres. The study area is located within the circle depicting the effective Doppler range of the Exeter operational weather radar.

Research on Great Lakes lake breezes and their effects has been conducted since the 1960's including seminal studies by Moroz (1967), Lyons (1972) and Estoque et al. (1976). Shenfield and Thompson (1962) were the first to suggest a link between Great Lakes lake breezes and severe thunderstorms. Chandik and Lyons (1971) found that the Lake Michigan lake breeze could either enhance and dampen thunderstorm intensity depending on the synoptic-scale conditions.

Recent studies have advanced our understanding of the relationship between lake breezes and severe weather in southwestern Ontario (King, 1996; King et al., 1996;

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Sills, 1998, King et al., 2002). These studies suggest that lake breezes have a considerable effect on the severe weather climatology of the region. In particular, lake breeze-related severe weather frequently occurs in association with a moderate southwesterly synoptic-scale wind regime delivering a warm, moist and convectively unstable air mass. Lake breeze circulations are deformed by the synoptic-scale flow so that lake breeze fronts oriented parallel to the flow (and to segments of the Lake Huron and Lake Erie shore) stretch far inland. It is not yet clear if these low-level boundaries remain attached to the lake breeze circulations.

In the Great Plains region of the United States, there have been several field studies examining the importance of low-level boundaries to the generation of severe weather. During a study on the High Plains in Colorado, Wilson and Schreiber (1986) showed that 79% of storms with radar reflectivities 30 dBZ or greater were initiated in association with radar-observed convergence lines. This increased to 95% for storms with radar reflectivities 60 dBZ or greater. During the VORTEX project in the southern Great Plains, Markowski et al. (1998) found that nearly 70% of observed tornadoes were associated with pre-existing, low-level boundaries.

Clearly, the ability to detect low-level boundaries such as lake breeze fronts and to predict their future behaviour is important for warm season severe weather forecasting and nowcasting.

Southwestern Ontario is an excellent natural laboratory for studying the relationship between low-level boundaries and severe weather. First, the region has the highest number of annual thunderstorm days (Kendall and Petrie, 1962) and the highest tornado incidence (Newark, 1984) in Canada. Damaging winds, hail, and heavy rain from thunderstorms are quite common spring and summer occurrences.

Secondly, several types of low-level boundaries are frequently observed in the region including lake breeze fronts and gust fronts. Lake breeze circulations can develop in the region on more than 50% of summer days and can penetrate more than 100 km inland (Sills, 1998). Lake breeze circulations from adjacent lakes frequently interact. The region also experiences the passage of synoptic-scale fronts on a regular basis through the summer months due to its mid-latitude location. This allows examination of the interaction of low-level boundaries with synoptic-scale fronts and the associated impact on severe weather.

Unlike gust fronts, lake breeze fronts are anchored to non-moving terrain features. This permits a first-order estimation of the positions of lake breeze fronts days in advance and allows instrumentation to be concentrated and field activities to be intensified in areas where lake breeze fronts are expected to occur. Also, lake breeze fronts typically move more slowly than gust fronts and can be quasi-stationary for several hours. This makes it relatively easy to obtain measurements along the front and in the air masses on either side.

MSC and York University conducted an ELBOW pilot study in 1997 (see King and Sills, 1998) and found that lake breezes influenced the timing, location and intensity of severe thunderstorms in several cases. The 2001 field experiment was more comprehensive and built upon the experience gained in 1997. The variety and quality of data collected make it the most thorough examination of the link between lake breezes and severe weather in the Great Lakes region to date. The following sections describe the ELBOW 2001 field experiment and discuss plans for future work.

3. EXPERIMENTAL DESIGN

The ELBOW 2001 field campaign ran from June 1 to August 31, 2001. Experimental instrumentation included the NRC Twin Otter research aircraft, a Cessna equipped with an Aventech instrument package, a 14 station mesonet, 4 rawinsonde systems, 2 wind profilers, a portable X-band (3 cm) Doppler radar, and mobile observation equipment. As shown in Figure 2, these instruments were used within the effective Doppler range of the MSC operational weather radar located in Exeter, Ontario. The Exeter radar is well-suited for detecting low-level boundaries in optically-clear air, typically out to 50 km but occasionally past 70 km. A special version of the MSC operational regional forecast model (GEM) with 2.5 km horizontal grid spacing was also run in real time in support of the experiment. Details of the high-resolution numerical models used for the experiment are discussed by King et al. (2002, this volume). Other operational data such as GOES visible satellite images, surface station measurements, rawinsonde profiles, data from nearby radars, and regional-scale numerical model runs were also used.

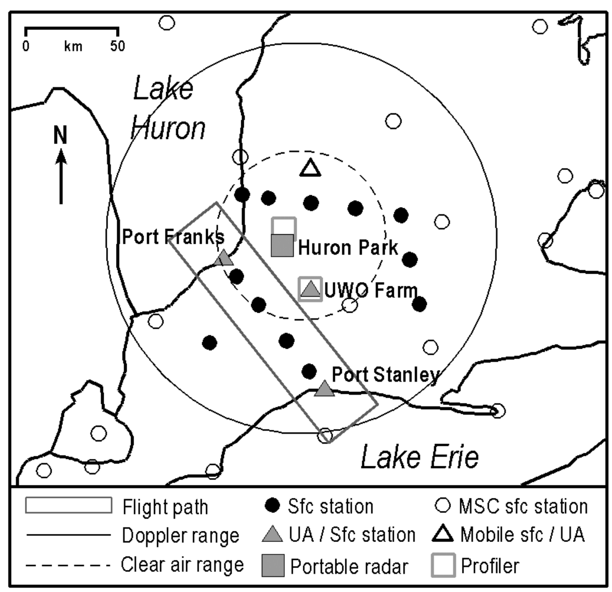

Figure 2. Map showing the location of instrumentation used for the ELBOW field campaign. Note that radar ranges are for the Exeter operational radar. Various scanning strategies were used with the portable radar depending on conditions.

The observational focal point was a transect from over Lake Huron to over Lake Erie that ran nearly perpendicular to the shores of these lakes and also to southwesterly synoptic-scale flow when present. The surface, upper-air and aircraft measurements made along this transect were intended to facilitate comparisons with high-resolution numerical modelling output through construction of vertical cross-sections of the lake breeze circulations through time. Lines of mesonet stations extending inland from the lakes to the northeast of this transect were intended to sample the lake breeze fronts when stretched well inland. It is hoped that these measurements will lead to an improvement in our understanding of the connection between lake breeze circulations and associated fronts in moderate wind regimes.

A mobile unit was also deployed on days of interest to make measurements across boundaries, record convective initiation, observe thunderstorms, and survey storm damage. Instrumentation included a portable rawinsonde unit, a portable surface station, a time-lapse video camera, and vehicle-mounted temperature, humidity and pressure sensors.

Project forecasters monitored the short- and long-range forecasts and issued daily status messages to the field teams. When forecast conditions appeared to be suitable, an Intensive Observation Day (IOD) was called and teams assembled in the project area. The Twin Otter aircraft was hangared at its home base in Ottawa, several hundred kilometres to the northeast, and was flown to the study region within 24 hours notice. The Aventech-equipped Cessna was hangared closer to the project area and could respond more quickly.

During a typical IOD, the project forecasters would conduct a 0800 EDT (Eastern Daylight Time) weather briefing for the field teams and would dispatch crews based on the conditions expected for the day. Radiosondes were simultaneously launched from each of the three upper-air sites at 1100, 1400 and 1700 EDT. Additional sondes were launched from the mobile unit when and where conditions warranted. Rawinsonde crews were deployed along pre-determined routes to make mobile measurements across lake breeze fronts between balloon releases. The mesonet stations produced averaged data every 5 minutes (the averaging interval for some stations was changed to 10 minutes through August). The MSC and UWO wind profilers produced averaged data every half hour. A radar operator ran the portable radar when conditions warranted. On days when desired project conditions were possible but unlikely, only partial measurements were made (e.g. 1 radiosonde launch instead of 9).

4. FIELD CAMPAIGN RESULTS

Summer 2001 was hot and unusually dry in southwestern Ontario resulting in frequent lake breezes but less severe weather than usual. Lake Huron and/or Lake Erie lake breeze circulations developed on at least 65 (or 71% of) study days. Another 11 potential lake breeze days, mainly under moderate wind regimes, will require further detailed examination for confirmation. Severe weather was reported in the study region on only 7 days but included tornadoes, hail, downbursts, and heavy rain. Severe weather occurred during daylight hours on 6 of the 7 days and, in at least 5 of these cases, it appears that severe thunderstorms were either initiated or enhanced at lake breeze fronts. These and other events of interest are listed in Table 1. Detailed analyses will be carried out for most of these cases to determine the role that lake breeze circulations played. It should also be recognized that days where lake breeze-related severe weather was expected but did not occur are important and will be studied in detail.

Date	Severe	IOD	Details
Jun 10	Yes	No	Line of storms with warm front crosses lake breeze fronts: wind damage
Jun 19	Yes	Full	Thunderstorms form along merged Erie and Huron fronts: large hail
Jun 20	Yes	No	Nocturnal bow-echo storm: wind damage
Jul 4	Yes	Full	Lake breeze fronts interact with cold front: tornadoes, large hail
Jul 16	No	Full	Lake breeze / warm front interactions result in brief rotating storm
Jul 19	No	Partial	Lake breeze fronts, ‘pulse’ storms and outflow boundaries
Jul 22	Yes	Full	Back-building storms along lake breeze front: large hail, flash flooding
Jul 23	Yes	Full	Lake breeze front / gust front interactions with ‘pulse’ storms: tornado, downburst, hail
Aug 19	Yes	No	Tornadoes develop at unidentified boundary, ‘cold low’ pattern

Table 1. Events of interest during the ELBOW 2001 field campaign. The table indicates the event date, if severe weather occurred, if there was an IOD, and the details of the event.

Overall, there were 29 IODs during the project, all within June and July. Radiosonde launches resulted in 178 successful profiles. Over 38 hours of aircraft time were logged; 29 hours with the Twin Otter and 9 hours with the Aventech-equipped Cessna. The mesonet data retrieval rate was generally quite high though persistent problems were encountered at one station. It was hoped that the portable X-band radar could assist with the detection of low-level boundaries in optically-clear air. However, it was found that the antenna gain was too low for this application. Instead, the radar was used to complement the Exeter operational radar though higher temporal resolution and the use of vertical storm scans (RHIs).

The high-resolution numerical models used for the project predicted the evolution of lake breeze circulations and the locations of lake breeze fronts with considerable skill. Modelled deep convection gave useful results in several cases but frequently lacked accuracy and precision. King et al. (2002, this volume) discuss model performance on several days of interest during the project.

Data from the ELBOW 2001 field campaign will be available for general use at the end of 2002. Please contact the lead author with questions regarding access to project data.

5. DISCUSSION AND CONCLUSIONS

Despite the near-drought conditions in southwestern Ontario during the summer of 2001, the ELBOW 2001 field campaign managed to capture a number of interesting events with interactions between lake breeze fronts and other low-level boundaries. On five days, lake breeze fronts appeared to initiate or enhance severe thunderstorms. Field operations went fairly smoothly, though the addition of a full-time nowcaster would have helped to ensure that aircraft flights and mobile measurements were made in the best possible locations. This was in the original plan but had to be withdrawn due to a limited number of field participants. The most difficult field task was predicting when favourable project conditions would occur. This was a particularly difficult (and stressful!) undertaking for Twin Otter aircraft callout since 24 hours notice was required and the number of project flight hours were limited. The project forecasters (Sills / King) have a better understanding of the state of the science with regard to lake breeze circulation / severe weather forecasting after having to make such forecasts on a daily basis. Having the field team and the aircraft located in the study region full time would have simplified operations and allowed greater interaction between the project scientists and the air team. However, the cost of this type of arrangement was prohibitive. Lastly, a greater number of mobile units would have allowed the capture of more storm data.

Future plans include the continued analysis of project data and the evaluation of project numerical models against observations. There will be considerable energy put into the transfer of scientific results to forecasters through training, tutorials, and operational prognostic tools. There are also long-term plans for an additional field campaign; this time including air chemistry measurements and possibly the participation of other interested researchers from abroad, including those from US states bordering the Great Lakes.

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REFERENCES

Chandik, J. F. and W. A. Lyons, 1971: Thunderstorms and the lake breeze front. Preprints, 7th Conference on Severe Local Storms, Amer. Meteor. Soc., 218-225.

Estoque, M. A.; J. M. Gross and H. W. Lai, 1976: A lake breeze over southern Lake Ontario. *Mon. Wea. Rev.*, **104**, 386-396.

Kendall, G. R. and A. G. Petrie, 1962: The frequency of thunderstorms days in Canada. Canada Department of Transport, Meteorology Branch, Toronto, Climatol. Study No. 4, 18 pp.

King, P., 1996: A long-lasting squall lined induced by interacting lake breezes. Preprints, 18th Conference on Severe Local Storms, Amer. Meteor. Soc., 764-767.

King, P.; A. Erfani, B. Murphy and D. Sills, 2002: The use of the GEM forecast model at very high resolution during ELBOW 2001. This volume.

King, P.; M. Leduc and B. Murphy, 1996: The climatology of tornadoes in southern Ontario: possible effects of lake breezes. Preprints, 18th Conference on Severe Local Storms, Amer. Meteor. Soc., 627-630.

King, P.; M. Leduc, D. Sills, N. Donaldson, D. Hudak, P. Joe and B. Murphy, 2002: Lake breezes in southern Ontario and their relation to tornado climatology. Submitted to Weather and Forecasting.

King, P. and D. Sills, 1998: The 1997 ELBOW Project: an experiment to study the Effects of Lake Breezes On Weather in southern Ontario. Preprints, 19th Conference on Severe Local Storms, Amer. Meteorol. Soc., 317-320.

Lyons, W. A., 1972: The climatology and prediction of the Chicago lake breeze. *J. Appl. Meteor.*, **11**, 1259-1270.

Markowski, P. M.; E. N. Rasmussen and J. M. Straka, 1998: The occurrence of tornadoes in supercells interacting with boundaries during VORTEX-95. *Wea. Forecasting*, **13**, 852-859.

Moroz, W. J., 1967: A lake breeze on the eastern shore of Lake Michigan: observation and model. *J. Atmos. Sci*., **24,** 337-355.

Newark, M. J., 1984: Canadian tornadoes, 1950-1979. *Atmos.-Ocean,* **22,** 343-353.

Shenfield, L. and F. D. Thompson, 1962: The thunderstorm of August 9th, 1961, at Hamilton Ontario. Tech. Rep. 417, Meteor. Branch, Dept. of Transport, Canada, 25 pp.

Sills, D.M.L., 1998: Lake and land breezes in southwestern Ontario: observations, analyses and numerical modelling. PhD thesis, York University, 338 pp.

Wilson, J. W. and W. E. Schreiber, 1986: Initiation of convective storms at radar-observed boundary-layer convergence lines. *Mon. Wea. Rev.,* **114**, 2516-2536.