

# **The Role of Multiple Lake Interaction in the Western New York Lake-Effect Snowstorm of 24-26 November 1991**

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## **ABSTRACT**

This paper presents a preliminary analysis of the 24-26 November 1991 lake-effect snowstorm which dumped from 25 to 50 cm (10-20 in) of snow in portions of western and central New York, and was observed by a network of sensors, including serial radiosondes, Doppler radar, and a wind profiler. Initial snowbands formed in southwest flow over and to the lee of Lake Erie and Lake Ontario. As the winds veered to more northwest, new bands formed over Lake Huron, extended southeastward, and were enhanced as they moved over the lower Lakes. It appears that a region of thermally induced convergence provided a favorable environment for the unusually heavy snowfall observed, as the enhanced Lake Huron bands dumped 25 cm (10 in) of snow in the Brockport area of western New York.

## **INTRODUCTION**

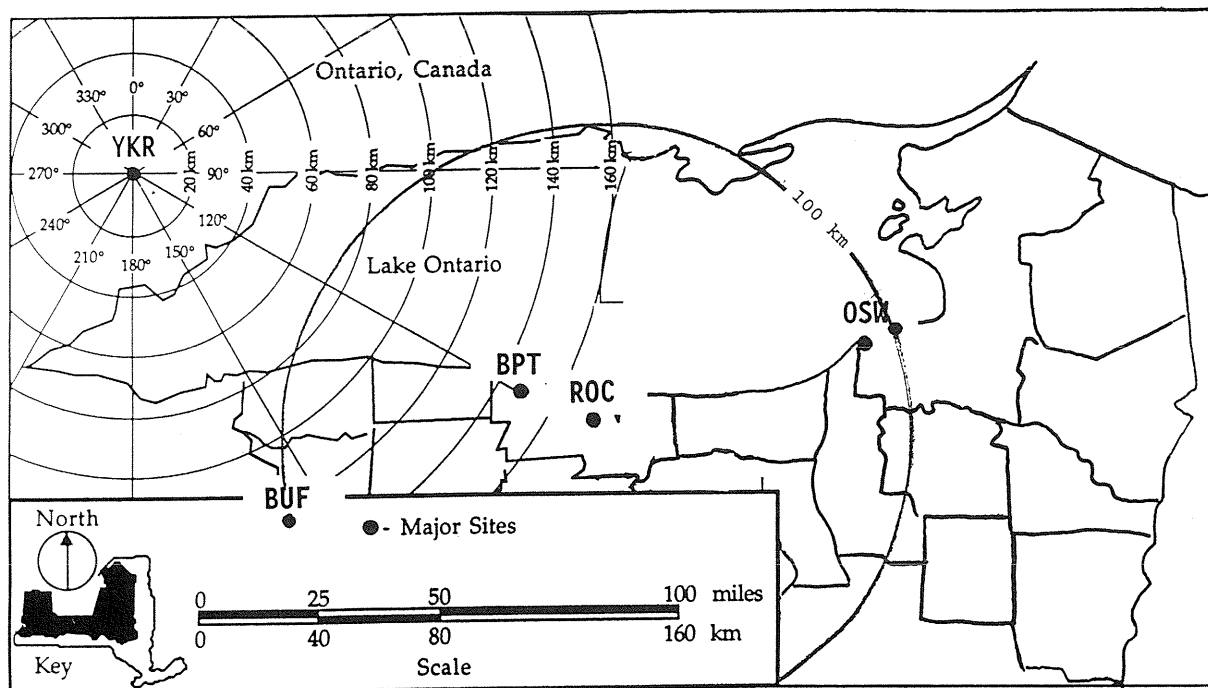
During the winter of 1991-92, the SUNY College at Brockport conducted a field program launching special soundings at Brockport and Oswego to observe the thermodynamic environments of lake-effect snow storms. During the same period, a variety of sensing systems was in place around the Lake Ontario region (Fig. 1), including the Atmospheric Environment Service Doppler radar at King City, Ontario, a 915 MHz wind profiler located near Oswego, NY, National Weather Service radars from Buffalo and Binghamton, NY, and a 5 cm radar operated by WOKR-TV in Rochester, NY. These data, combined with synoptic, satellite and

meteorological tower data are being analyzed in diagnostic case studies of six events which took place during the 1991-92 winter season.

Traditional lake-effect snow storms which occur to the lee of the Great Lakes have been extensively documented (e.g. Peace and Sykes, 1966; Braham and Kelly, 1982; Niziol, 1987 and Reinking, et.al., 1991). The LOWS project showed the utility of state-of-the-art sensing systems for diagnostic study of lake-effect snowstorms (e.g. Reinking, et.al., 1991; Byrd and Penc, 1992; and Penc, 1992). However, little attention has been given (e.g. Niziol, 1987) to interaction between the lakes in producing lake-effect snow storms. The 1991-92 data set is a good one for study of multiple-lake interactions, as three of the six lake-effect events (24-26 November, 18 January and 12-14 March) show bands which originated over Lake Huron and were either reformed or enhanced as they passed over Lake Ontario. This paper presents the results of preliminary analysis of one such case, which occurred 24-26 November 1991.

## **THE 24-26 NOVEMBER 1991 LAKE-EFFECT EVENT**

The lake-effect storm of 24-26 November 1991 dumped 25-50 cm (10-20 in) of snow over portions of western and central New York, to the lee of Lake Erie and Lake Ontario (Fig. 2). The utility of high resolution numerical model output for forecasting this event is discussed by Niziol (1992). This event can be divided into 2 distinct episodes. The first comprises the initial lake-effect snow bands which developed in west-southwest flow off Lakes Erie and Ontario and deposited significant snow on the lee



**MAJOR SITES:**

- Brockport (BPT): Sounding site.
- King City (YKR): C-Band Doppler Weather Radar
- Buffalo (BUF): S-Band Weather Service Radar, Sounding Site
- Rochester (ROC): C-Band Weather Radar (WOKR-TV)
- Oswego (OSW): 915 MHz Wind Profiler, Sounding Site, RASS.

Figure 1. Sensor array in the Lake Ontario region for the 1991-92 field study. Range Circles are for the King City Doppler and the Rochester WOKR-TV radars.

(eastern) shores. This was followed by the development of snowbands off Lake Huron as the flow became northwest. These bands appear to have undergone an enhancement when passing over Lake Erie and Lake Ontario, and are of primary interest in this study. This paper will document the evolution of the lake-effect episode through King City radar plots of reflectivity (Fig. 3a-d), time series plots of King City Doppler velocity azimuth display (VAD) winds (Fig. 4), and Oswego profiler wind data (Fig 5). Time-height cross-sections of temperature derived from serial soundings taken at 6 hour intervals at Buffalo and Brockport are shown in Fig. 6. All of these data are in qualitative agreement as to the evolution of the kinematic and thermo-dynamic environment in the lower troposphere during this episode. A more detailed discussion is contained in the following sections.

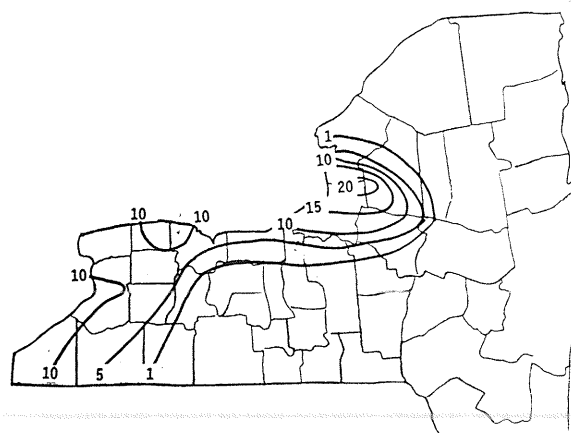


Figure 2. Snowfall (in.) in western and central New York for 24-26 November 1991.

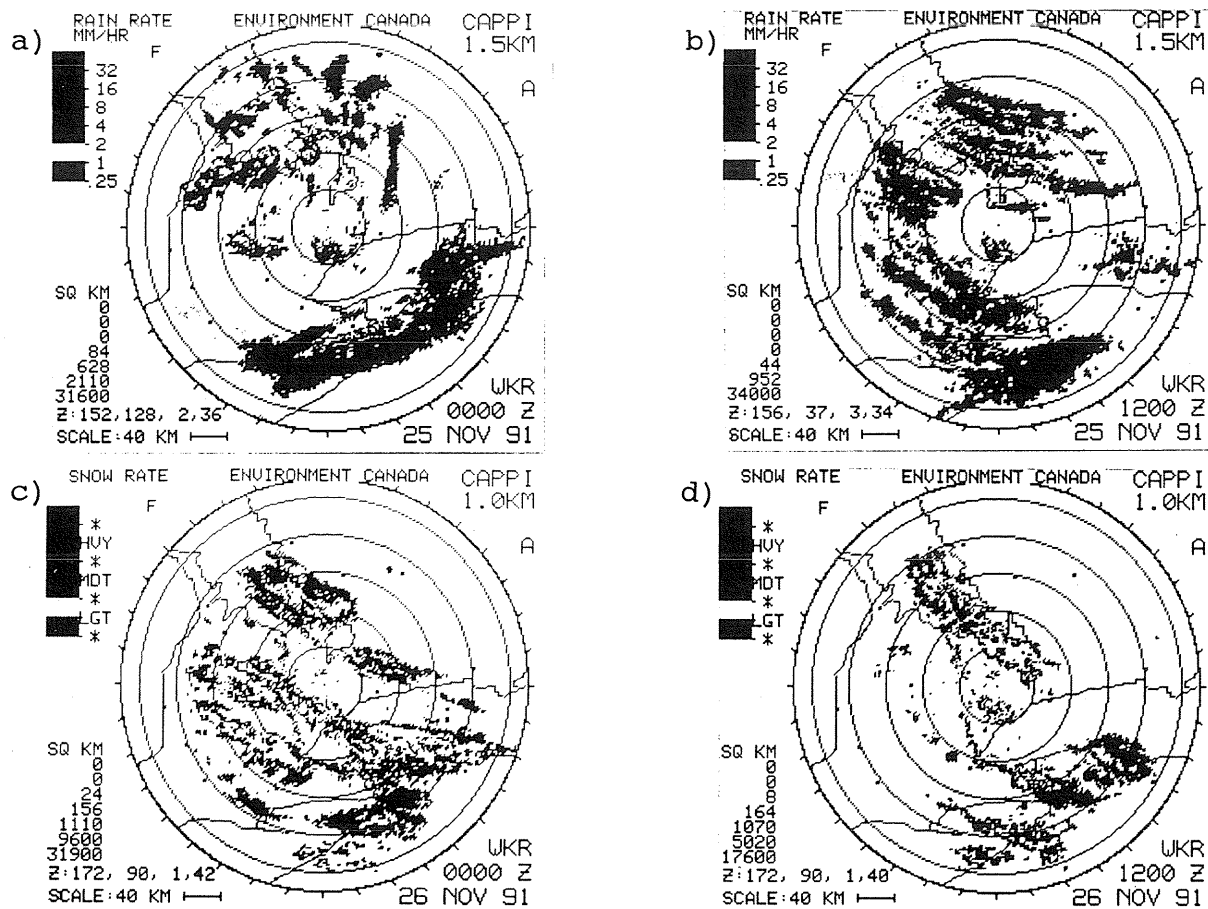


Figure 3. Low level (1 to 1.5 km) Constant Altitude Plan Position Indicator (CAPPI) displays of reflectivity (snowfall /rainfall rates) from the King City Doppler radar for a)0000 and b)1200 UTC on 25 November and c)0000 and d)1200 UTC 26 November 1991.

### Initial Bands off Lake Erie and Lake Ontario

The onset of lake-effect snow occurred between 1200 and 1800 UTC on 24 November, as snowbands developed off of Lake Erie in the vicinity of Buffalo. The 1200 UTC surface analysis (Fig. 7a) shows that these bands were oriented along the southwest flow of polar air in the boundary layer, in association with an occluding 996 mb surface low over Western Ontario. The Doppler VAD (Fig 4) and the Oswego profiler data (Fig. 5) show that the southwest flow possessed minimal directional shear in the lowest 3 km, producing an environment favorable for intense single snowbands (Niziol, 1987). Lake-effect instability was marginal at this time with a lake/850 mb temperature difference of 13 C. Between 1200 and 0000 UTC, serial soundings show the depth of the conditionally unstable boundary layer increased from 2.0 to 2.7 km (Fig 6), while the VAD (Fig.4)

and the profiler (Fig. 5) data show that the winds had begun to veer to a west-southwest direction, with the Oswego wind shift lagging the King City shift by some 4-6 hours.

By 0000 UTC on 25 November, moderate to heavy lake-effect snow activity was being observed by radar in a 50 km wide SW-NE oriented band over portions of Buffalo, Erie and Niagara Counties to the lee of Lake Erie (Fig. 3a), and significant snowfalls were also commencing in the Tug Hill Plateau to the lee of Lake Ontario. The squalls were accompanied by occasional reports of thunder and lightning, with visibility reduced to 1/8 mile in a heavier snowburst at Buffalo about 0100 UTC. The soundings (Fig 6) revealed that the boundary layer deepened to 3.2 km by 0600 UTC, in part due to cyclonic vorticity advection associated with a 500 mb short wave trough which was migrating through the region.

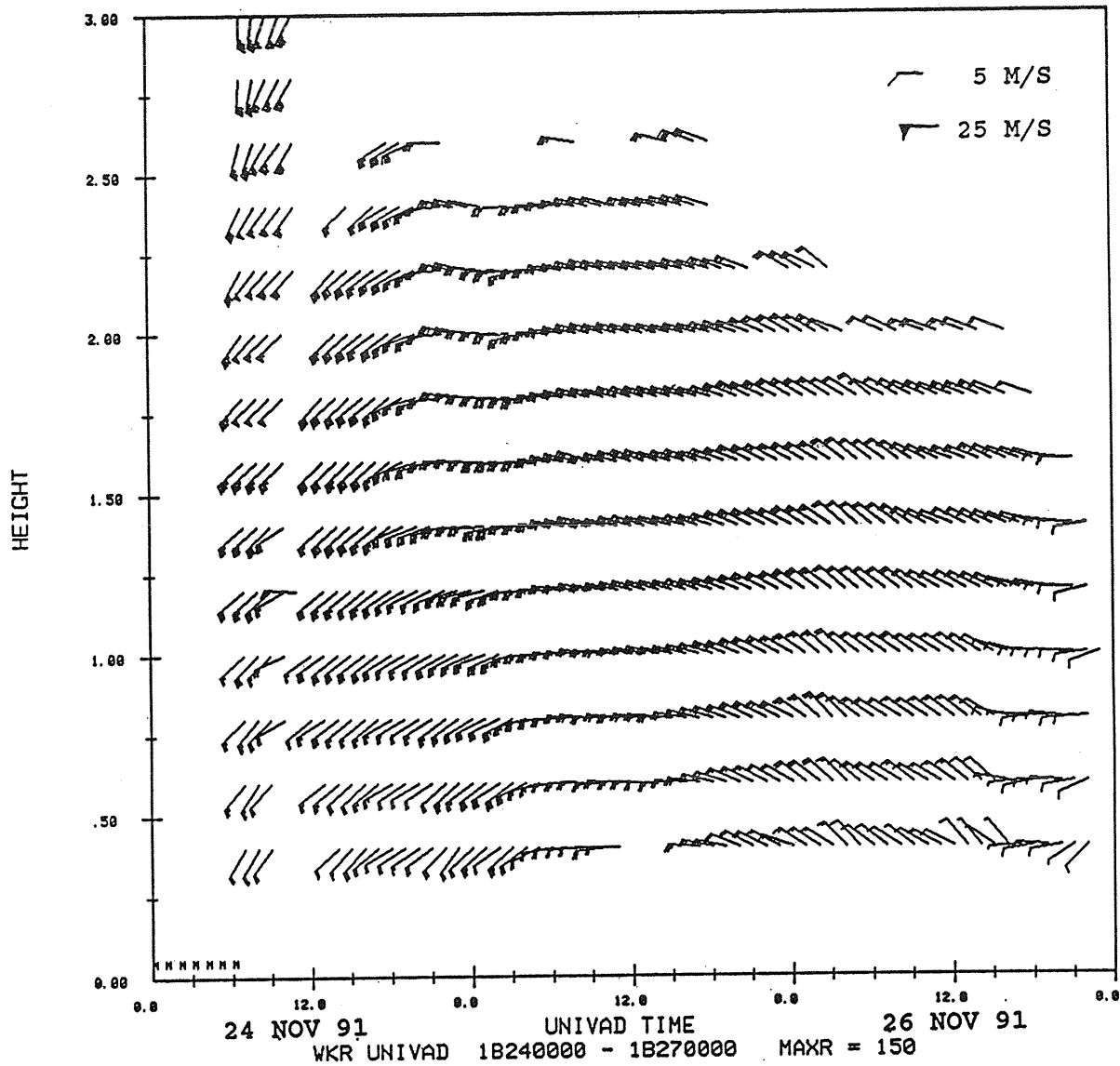


Figure 4. Time-height section of King City Doppler VADs for the period 0000 UTC 24 November to 0000 UTC 27 November 1991

With trough passage the boundary layer depth decreased to about 2.7 km by 1200 UTC. Between 0000 and 1200 UTC, both the VAD and profiler winds showed a gradual veering to a west direction, with maintenance of a minimal directional shear in the boundary layer. Snowfall through 1200 UTC on 25 November totalled as much as 38 cm (15 in) in the Lancaster and Depew areas to the lee of Lake Erie, while 55 cm (22 in) was reported in the Tug Hill region to the lee of Lake Ontario.

#### Lake Huron Bands Enhanced by the Lower Lakes

By 1200 UTC on 25 November, the surface low (Fig. 7b) had deepened slightly (to 994 mb) and had moved into Quebec. Between 1200 and 0000 UTC the boundary layer flow depicted by the King Doppler VAD (Fig. 4) continued to veer around to the northwest. Veering was also observed in the Oswego profiler (Fig. 5), but continued to lag the King City shift by 4-6 hours. Low level cold advection had rendered the atmosphere conditionally unstable for lake-effect, with a lake/850mb

temperature difference of 17 C. Between 1200 UTC and 0000 UTC, the boundary layer continued to become shallower, decreasing to a depth of about 2.0 km (Fig. 6). Between 1200 and 1800 UTC (Fig. 3b), 30-50 km wide west-northwest to east-southeast oriented snow bands, spaced 60-80 km apart, developed to the lee of Georgian Bay and Lake

Huron, while the previous band was dissipating along the south shore of Lake Erie. A 1800 UTC low-level PPI of radial velocity from the King City radar (not shown) indicated stronger northwest flow outside of the bands, with a pronounced weakening of the flow within the bands themselves. The slower wind speed within the band is likely due to upward transport of

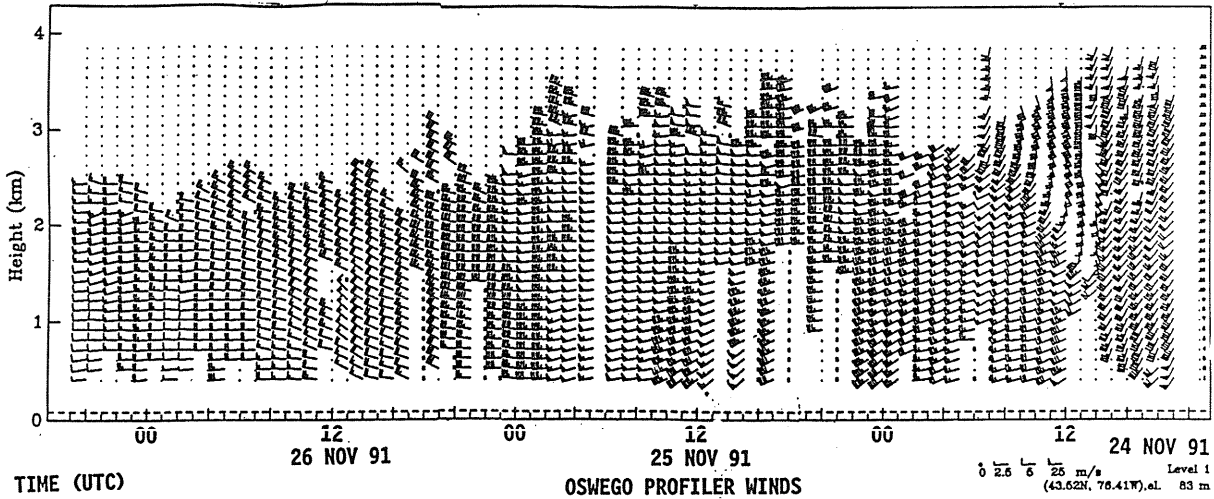


Figure 5. Time-height section of Oswego 915 Mhz profiler winds for the period 0000 UTC 24 November to 0000 UTC 27 November 1991.

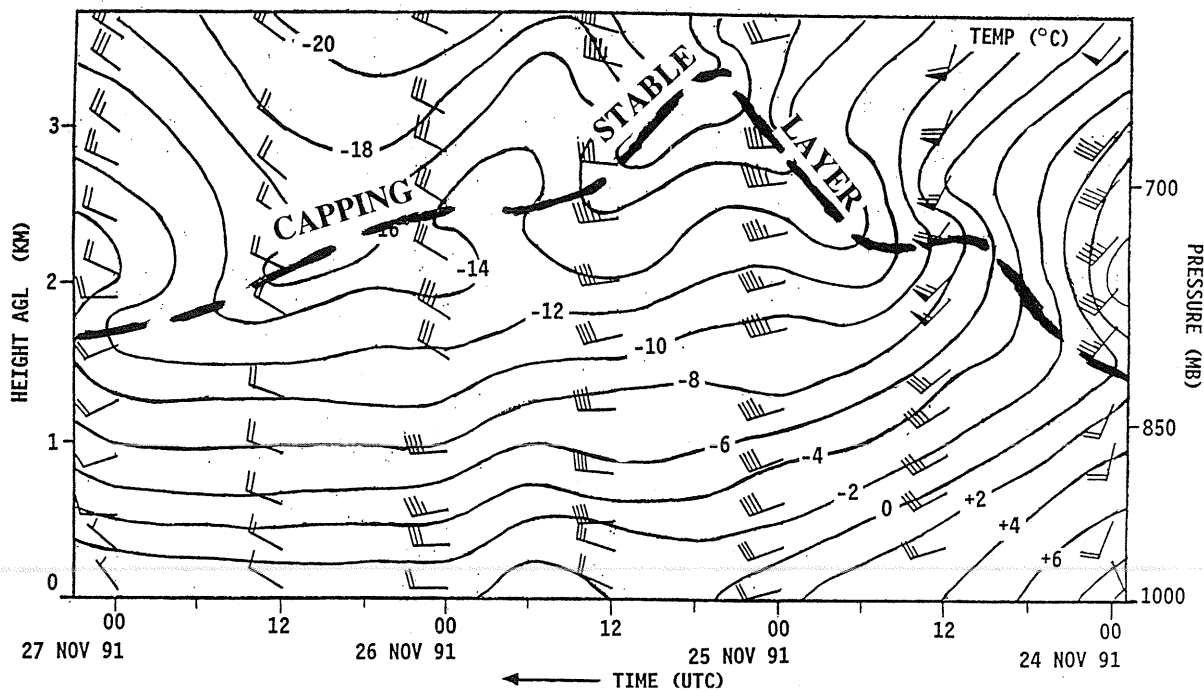


Figure 6. Time height section of serial soundings from Buffalo and Brockport for the period 0000 UTC 24 November to 0000 UTC 27 November 1991.

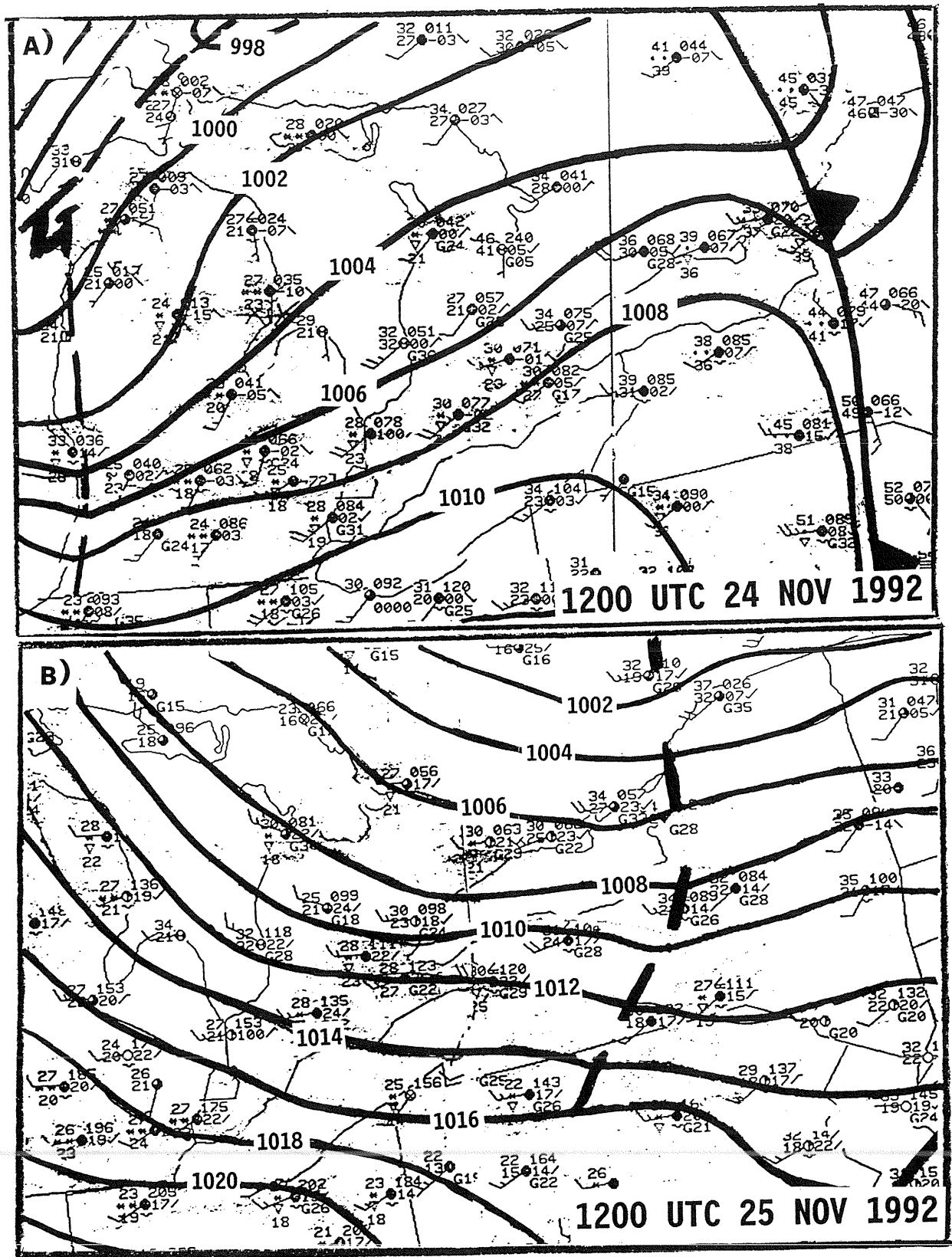


Figure 7. Surface analyses for a) 1200 UTC 24 November, b) 1200 UTC 25 November and c) 1200 UTC 26 November 1991.

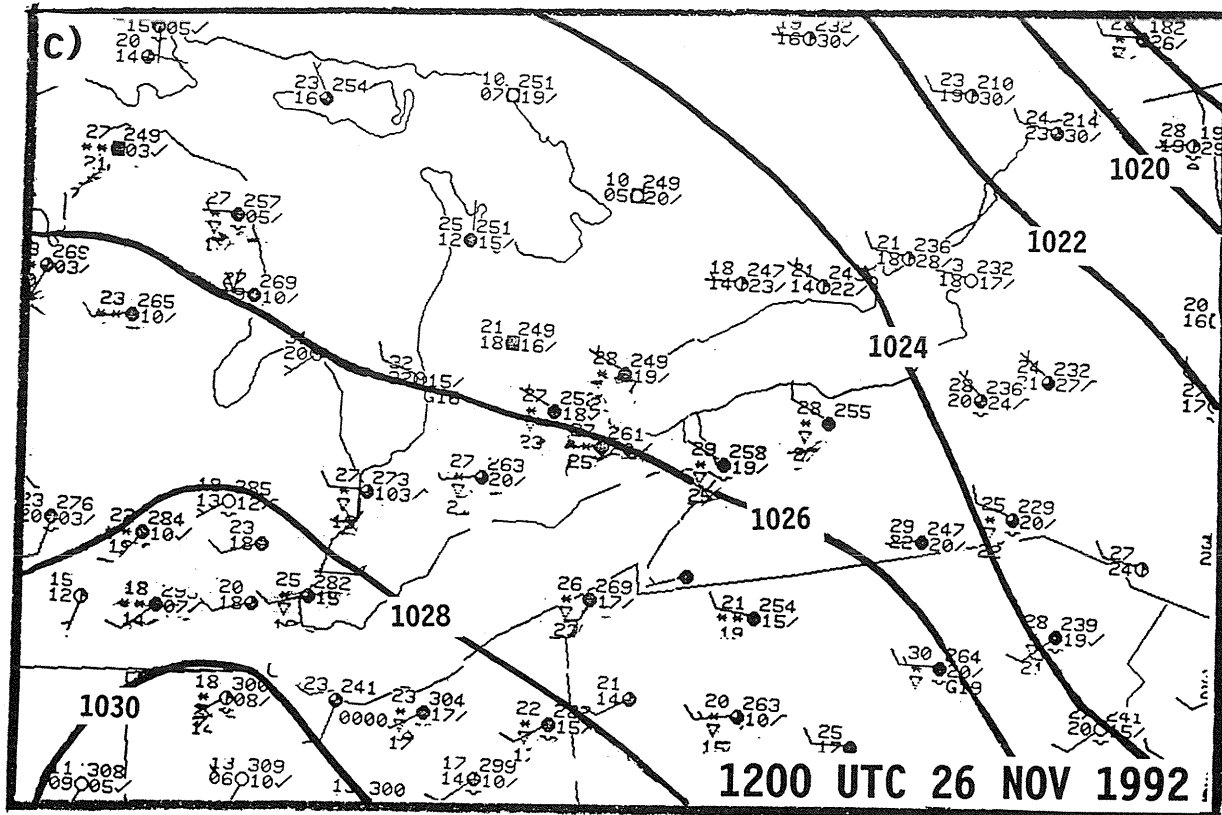


Figure 7 (continued)

low momentum air near the surface due to convergence, while the stronger winds outside of the band can be explained by downward transport of higher momentum air within the descending branch of the roll circulation associated with the bands.

By 0000 UTC on 26 November, moderate lake-effect instability was observed (lake/850 mb temperature difference of 20 C) over the Eastern Great Lakes and two bands off of Georgian Bay and Lake Huron, roughly separated by the Bruce Peninsula, appear to have been enhanced as they travelled over Lake Ontario and the eastern portion of Lake Erie (Fig 3c). This resulted in moderate to heavy snowfalls over Niagara, Orleans and western Monroe Counties of New York State. Vorticity advection associated with a weak 500 mb short wave which passed through the region may also have contributed to the enhanced snowfall activity. Between 0000 and 1200 UTC, snowfall rates of up to 2 inches per hour were observed in the Brockport area, while boundary layer depth (Fig 4) was maintained at 2.0 to 2.2 km. During this period,

profiler and VAD winds showed a continuation of northwesterly flow in the boundary layer, but with more directional shear evident in the King City observations just prior to 1200 UTC. The Lake Huron bands, enhanced by Lake Ontario (Fig. 3d), deposited 25 cm (10 in) of snow in the Brockport area during this period.

By 1200 UTC on 26 November, the surface low had undergone explosive deepening to 967 mb over the Canadian Maritimes, resulting in a northwest flow over the Eastern Great Lakes (Fig. 7b). Conditional lake-effect instability (lake/850 mb temperature difference 17C) remained over western New York, as the NW-SE oriented Georgian Bay/Lake Huron snowbands continued to be enhanced by Lake Ontario through 1200 UTC on 26 November (Fig 3d). Soon thereafter, these bands began to dissipate as surface ridging introduced west to southwest flow at low levels increasing directional wind shear in the boundary layer, as evident on both the King City VAD (Fig.4) and Oswego profiler (Fig. 5) plots.

## DISCUSSION

The initial Lake Erie and Lake Ontario bands formed in conjunction with the destabilization of polar air flowing over the warm lakes. Instability was modest but extended over a considerable depth (up to 3.2 km), and, when combined with small directional shear in the boundary layer produced a favorable environment for heavy single bands to the lee of each lake.

Of greater interest is the forcing mechanisms responsible for producing the unusual heavy snowfalls in western New York from snow bands which originated off of Lake Huron. Between 0000 and 1200 UTC on 26 November, the regional surface temperature analysis revealed a warm plume of air extending from Lake Huron into western New York (Fig 8a) in approximately the same location as the observed snowband activity. While some of this modification was due to boundary layer warming by the lake, diminished longwave radiative heat loss in the lake-effect cloud region was a contributing factor as well, as evidenced by strengthening of the warm anomaly during the nighttime hours. Fig 8b shows the corresponding surface divergence field for the same time. There is a well defined area of surface convergence peaking at nearly  $2.0 \times 10^{-4} \text{ sec}^{-1}$  extending from Lake Huron into western New York. This area coincides nicely with the warm anomaly and the observed snowband activity. The surface convergence pattern eventually became disorganized and eventually dissipated between 1200 and 0000 UTC, coincident with the demise of the snowband activity.

It appears, then, that thermally induced convergence in the boundary layer may have played a significant role in the initiation and maintenance of a favorable environment for an extended period of moderate snowfall in western New York from snow bands originating over Lake Huron. This, combined with some enhancement by Lake Ontario, weak cyclonic vorticity advection aloft and local topographic forcing was crucial to the maintenance of a boundary layer and associated lake-effect clouds of sufficient depth (2 km) to produce the observed moderate to heavy snowfall rate. It should be noted that the boundary layer instability was modest in this case, yet heavy snowfalls were observed, lending further credence to the contention of Byrd, et. al. (1991) and Byrd and Penc (1992) that the depth of the boundary layer may often be of greater importance than the amount of instability in modulating the intensity of lake-effect snow events.

The elevated terrain and increased roughness of the Bruce Peninsula set up a divergence pattern that probably contributed to the observed spacing of the Lake Huron bands, but the horizontal scale of that divergence pattern was too small to be detected in the analysis presented in Fig 8.

## CONCLUDING REMARKS

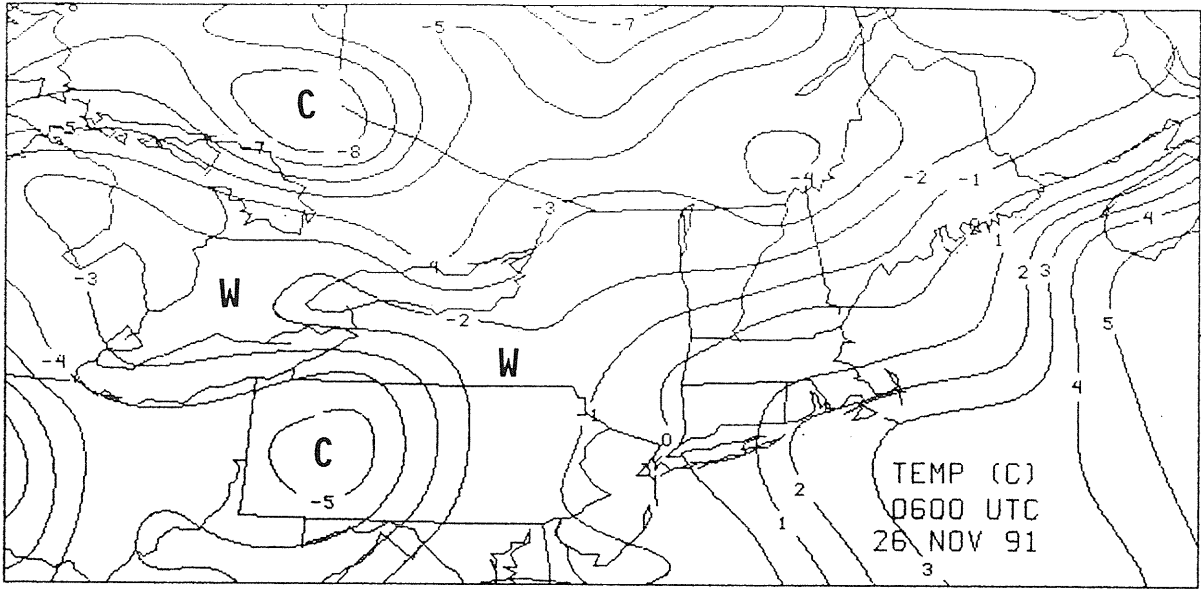
The preliminary results of this study show the utility of an array of state-of-the-art sensing systems for diagnostic studies of lake-effect snow events involving multiple lake interaction. We plan to continue study of this case and other 1991-92 cases to gain a better understanding of the forcing mechanisms which modulate these lake-effect events. Many questions remain as to the role that topographic features such as the Bruce Peninsula played in this event, and how much of an influence Lake Ontario played on the downwind enhancement of these snow bands. These and other related questions can only be answered by collaborative numerical modelling efforts which we are currently embarking on with meteorologists at SUNY Oswego (see Ballentine, et. al. 1992) and the National Weather Service Forecast Office at Buffalo. This combined case study and modelling approach will continue to enhance our understanding of the structure and dynamics of lake-effect snows in general, but will be especially useful in shedding light on the less-well-documented interactions between the lakes. Increased understanding resulting from these studies will no doubt enhance the predictability of lake-effect snowbands which continue to challenge the operational forecasting community.

## ACKNOWLEDGMENTS

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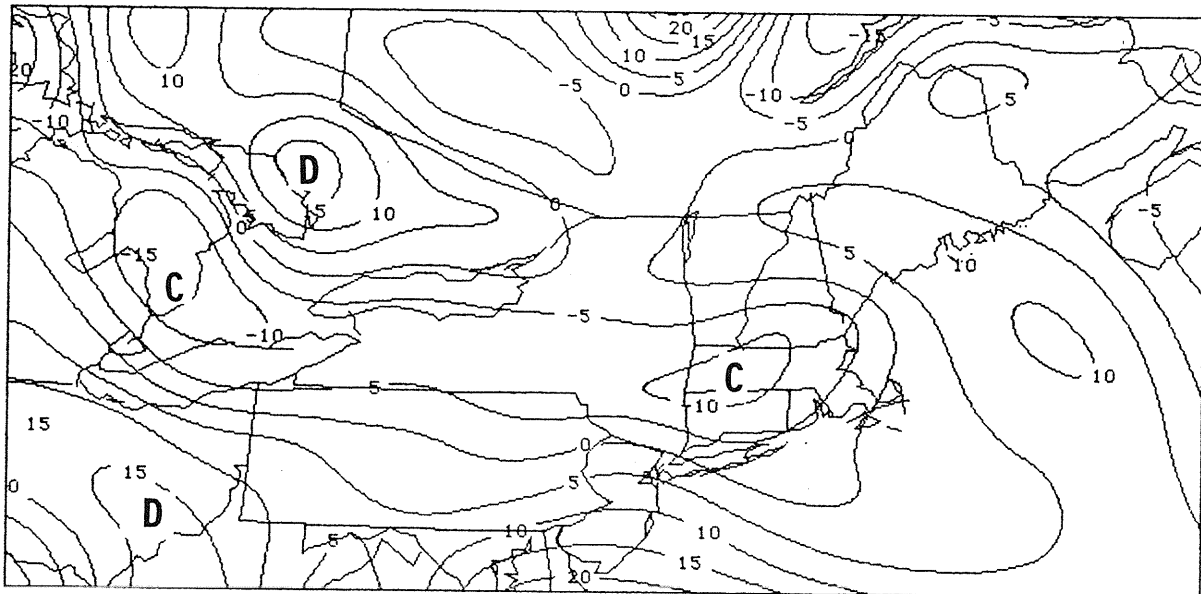


A)



T (C) TIME 6. DAY 91330. SFC

B)



DVG TIME 6. DAY 91330. SFC SFC DIVERGENCE 0600 UTC 26 NOV 91

Figure 8. Analysis of a) surface temperature and b) surface divergence ( $10^{-5} \text{ sec}^{-1}$ ) for 0600 UTC on 26 November 1991.

Weigelt of Galson Corporation graciously provided the profiler data. Mary Beth Wrobel contributed to the initial data analysis. The tireless voluntary efforts of numerous SUNY Brockport undergraduates who support our field programs are greatly appreciated.

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