

A Comparison of Two Lake Breeze Severe Events with a Threat Checklist Application

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1. Introduction

Lake breeze initiated thunderstorms are very common across west-central New York (NY) and northern Ohio (OH). Severe thunderstorms producing damaging winds in excess of 25 ms^{-1} (50 kts.), large hail greater than 1.9 cm in diameter, or even tornadoes may occur with lake breeze boundaries (Wolf, 2004; King et al., 2003; Sills et al., 2002). Occasionally, lake breeze boundaries and their associated strong to severe convection migrate eastward from Lakes Ontario and Erie into eastern NY and western New England. Two distinct lake breeze severe weather events occurred on 9 August 2001 across upstate NY and western New England, and 19 April 2002 over northern and central OH. This poster presentation will briefly compare the synoptic, mesoscale, and storm-scale environments of these two events. Finally, these two cases are included in an 11-case dataset from 2000-2006, where a lake breeze flow chart and threat checklists have been developed (Wilson, 2008) from the Collaborative Science, Technology, and Applied Research (CSTAR) program.

2. Data

Data analyzed include 40-km RUC, 32 and 80-km ETA and 2-km WRF (for one case) model grids, surface observations, upper air data, satellite imagery, and Weather Surveillance Radar – 1988 Doppler (WSR-88D) radar data. The WSR-88D data is 8-bit data from KENX and 4-bit data from KCLE. SPC upper air charts and soundings will also be used (www.spc.noaa.gov) from the severe weather thunderstorm archive.

3. August 9, 2001 Lake Breeze Severe Case

Lake breeze severe weather cases impacting eastern NY and western New England are very rare. On 9 August 2001, however, a strong lake breeze boundary moved east of Lake Ontario during the mid to late afternoon into the National Weather Service at Albany county warning area. Severe convection developed downstream of Lake Ontario and along and just north of the Mohawk River Valley (Fig. 1) knocking several trees and power poles down and producing two large-hail reports in excess of 3.5cm (Fig. 2). The cluster of severe thunderstorms developed in a very hot and humid air mass, where surface temperatures exceeded 35°C , and surface dewpoints were greater than 20°C .

The 500 hPa flow exhibited flat ridging over southeastern Canada and the Northeast with a short wave trough passage earlier in the morning (Fig. 3). Upstream 500 hPa temperatures over Wisconsin and Michigan were about -5°C . A stronger upper-level trough was displaced upstream over the Manitoba-Ontario border at 1200 UTC. The mid-level flow was very weak over western NY and PA with $5\text{-}7.5 \text{ m s}^{-1}$ (10-15 kts). 500 hPa heights over the region exceeded 585 decameters (dam). Synoptic ascent was weak with the ridge axis upstream of Albany. The mid-level thicknesses were very warm with values greater than 576 dam over the entire region (Fig. 4a). The Eta indicated the Bermuda high would be ridging in from the south and west with increasing heights (Fig. 4b). Upstate NY was on the anticyclonic shear side of the upper level jet (Fig. 4c). 850 hPa theta-e values from the initial analysis of the Eta were 335-350 K with the highest values downstream of Lakes Erie and Ontario. The low-level Θ_e ridge axis extended north from western PA. 850 hPa dewpoints were around 15°C near Buffalo (KBUF) and temperatures at that level across the Northeast were about 20°C (not shown).

The mesoscale environment based on the KBUF sounding at 1200 UTC was unstable with just a weak low-level inversion in the boundary layer (Fig. 5). The surface based convective available potential energy (SBCAPE) value exceeded 1500 J kg^{-1} with a

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Convective Inhibition of 184 J kg^{-1} . The downdraft CAPE (DCAPE) was also very high at 1131 J kg^{-1} , which indicates the potential strength of the rain-cooled downdrafts in thunderstorms. The Level of Free Convection (LFC) was a bit high at 2.6 km (755 hPa). The winds through the troposphere were light with a deep layer shear (0-6 km) value of 4 ms^{-1} (8 kts.) or less. Past work shows a lower LFC and favorable directional shear in the 0-2 km layer may support strong convection with lake breezes off Lake Erie (Kristovich et al., 2003). The study showed that thunderstorms tended to be more intense near the lake breeze front when the low-level wind shear was oriented opposite the southward moving boundary. The 1000-700 hPa shear at KALB at 1200 UTC was 10 ms^{-1} (20 kts.). The KBUF sounding had a precipitable water value of 46 mm which indicated the appreciable moisture in the low-levels. Further upstream, the deep shear did not appear strong enough for potential supercells (Thompson et al., 2003), but was more pronounced with the late afternoon KALB sounding (Fig. 6) having a 0-6 km shear values of 15 ms^{-1} (30 kts.). An abundance of instability (SBCAPE greater than 5000 J kg^{-1}) was in place over Albany with surface dewpoints in excess of 20°C and air temperatures peaking at about 35°C . The low- and mid-level lapse rates were also very steep for KALB. KSYR reached 38°C by the early afternoon.

An hourly analysis of the 40-km RUC of 2 m dewpoints and temps and 10 m winds across NY showed a lake breeze boundary migrated eastward from Lake Ontario between 1600-1900 UTC (not shown). The difference between the Lake temperature ($\sim 25^\circ\text{C}$) and neighboring surface observations ranged from $5\text{-}10^\circ\text{C}$. The wind shift was very distinct as the developing line of convection moved east, as seen in the visible satellite picture at 1845 UTC (Fig. 7a). A full blown Mesoscale Convective System (MCS) developed as it approached the Mohawk Valley and the Adirondack region (Fig 2.). The MCS produced widespread wind damage and one cell produced very large hail. This MCS moved into theta-e rich air that exceeded 350 K over eastern NY and large SBCAPE ($>2500 \text{ J kg}^{-1}$).

The storm-scale structure of the cluster convection that fired due to the lake breeze was very impressive. A supercell formed over southern Herkimer County with vertically integrated liquid values in the $70\text{-}80 \text{ kg m}^{-2}$ range from 2140-2210 UTC. At 2156 UTC, the 0.5° KENX base reflectivity scan had 65 dBZ over south-central Herkimer County in the Mohawk Valley (Fig. 8a) with an elevated reflectivity core of 65+ dBZ over 30 kft (Fig. 8b). The wet bulb zero heights were in the 12-13 kft

range. Hail was reported from ping pong ball to hen egg size (3.8-5.0 cm). The echo tops product showed max tops in the 55-60 kft AGL range at 2156 UTC (not shown). A strong, shallow mesocyclone also briefly formed at 2146 UTC (35 kts. of rotation with a shear value of 0.038 s^{-1} in the lowest tilt) and sporadically continued through 2210 UTC. No tornado warnings were issued or reported, despite a supercell with hail monster characteristics. Microburst damage continued from 2215 UTC to 0100 UTC across eastern NY and western New England, and portions of New England continued to have sporadic damage from the MCS prior to 0400 UTC 10 August 2001.

4. April 19, 2002 Ohio Lake Breeze Severe Case

On 19 April 2002, a lake breeze boundary, interacting with a southward-moving strong cold front, spawned a supercell in northwest OH. This storm resulted in numerous hail reports, one of which was about 5 cm in diameter, and an F0 tornado (Fig. 9).

The upper air analysis showed a 500 hPa high amplitude ridge over the East Coast with southwesterly flow over the Midwest and Central Plains (Fig. 10). A cutoff low is centered over the Great Basin with a progressive short wave trough pushing equatorward from south central Canada into the Upper Great Lake region. A region of upper-level confluence is in place over the Midwest and Ohio Valley. The mid-level temps are fairly mild for mid-April over the Lower Great Lake region. Flow at the 200 hPa level is also quasi-zonal (southwesterly) upstream of the long wave ridge over the eastern half of the lower 48 (Fig. 11). Much of OH is dominated by the right exit region of the upper level jet streak, which is not typically conducive for strong convective development. It appears portions of the Upper Great Lakes region into Canada would have the better chance for upper level dynamics to initiate strong to potentially severe convection (left exit region of the jet streak). Despite the unfavorable mid- and upper-level dynamics, a surface cold front and cyclonic vorticity advection from the short wave trough were forecasted to break the record warmth over the lower Great Lakes region (not shown). The sultry low-level theta-e ridge showed up nicely at 850 hPa with values greater than 320 K from OH south and east ahead of the cold front (Fig. 12). An 850 hPa trough can be viewed north of the ridge with a very broad baroclinic zone draped on the western periphery of the ridge. By the late morning, the surface cold front and its associated baroclinic zone were approaching northwest OH.

The mesoscale environment showed a more volatile environment for potential convection. A

cross-section from the ETA from southern Ontario through the Ohio Valley showed a broad region of convective instability with very high θ_e at the surface decreasing with height up to the mid-levels (not shown). This deep layer of low to mid-level instability from the ETA was supported by the nearest environmental sounding to OH. The 1200 UTC Pittsburgh (KPIT) sounding (Fig. 13) confirmed weak to modest deep layer shear (0-6 km shear of 30 kts.) with moderate instability to 1700 J kg⁻¹. The shear was marginal for supercells. The CIN was 112 J kg⁻¹ with an LFC of about 2.1 km (736 hPa). The low-level lapse rates in the 0-3 km layer were steep at 7°C km⁻¹, while the mid-level lapse rates were marginal at 6.5°C km⁻¹. The precipitable water value on the KPIT sounding was 24.9 mm. Overall, it appeared buoyancy forces were favored over deep shear and upper-level dynamics for strong to severe convection.

By 1900 UTC coastal surfaces temperatures climbed past 28°C, a good 10-15°C above normal for mid-April. Meanwhile, the Lake Erie water temperatures were around 13°C. A strong lake-land thermal gradient of about 15°C existed. A 2-km WRF forecast cross-section valid at 1900 UTC showed the rising motion over the land with strong sinking motion over the lake (Fig. 14). The surface cold front was also lurking to the north and west, and a lake breeze began moving south/southeast into Ohio. The interaction between the lake breeze and the synoptic cold front helped fire severe convection with a tornadic supercell.

Multiple boundary interactions helped focus the severe convection. Initially, numerous cells fired along the lake breeze (not shown). Many of these cells were weak with a few marginal severe hail reports. The cold front at the surface was beginning to move into northern OH after 2000 UTC. It was basically catching up to the lake breeze. One storm began to show supercellular characteristics over the next hour (Fig. 15). The KCLE Radar Velocity Azimuthal Display wind profile showed low-level veering in the boundary with this cell. The veering winds allowed stronger directional shear (or low-level helicity) coupled with the abundance of instability for the supercell to form.

The supercell produced large hail prior to the F0 tornado (Fig. 9). A bounded weak echo region and potential hook echo formed. Reflectivity cross-sections showed high reflectivities (greater than 60 dBZ) above 3 km (above the freezing level). Overshooting tops rose above 15 km (above the tropopause). The 2111 UTC 0.5° KCLE velocity and storm relative motion images were masked by range folding (purple haze) on the inflow side of the rotational couplet. However, the 2118 UTC velocity

image at 1.5° slice showed strong cyclonic convergence (cyclonic rotation implied) with a mesocyclone and tornadic vortex signature (not shown). The rotational couplet reached 25 ms⁻¹ (50 kts.) gate to gate. A report of a tornado was recorded at 2116 UTC.

The storm weakened and phased with a multicellular cluster of convection. From the radar analysis, we can speculate the cold front interacted with the lake breeze boundary by providing increased horizontal shear, combined with a potent updraft (due to the strong buoyant forces implied by the environmental instability from the KPIT sounding) to allow this supercell to develop a mesocyclone. The mesocyclone was fairly shallow below 10 kft (not shown). A 2-km WRF cross-section showed strong low-level ascent below 700 hPa at 2100 UTC (not shown). The ascent favored vortex stretching at the low-levels, while the descent above 700 hPa would result in vortex relaxation and a reduction of cyclonic vorticity in the thunderstorm updraft. This case shows a strong contrast to the 9 August 2001 case in terms of the synoptic environment.

5. Discussion and Summary

In a survey of 11 lake-breeze induced convective events, Wilson (2008) categorized pure cases as lake-/sea-breeze convergence zones generating severe convection in the absence of synoptic-scale forcing. The 9 August 2001 severe case fell into this category. Mixed cases involved synoptic-scale forcing in conjunction with the mesoscale forcing from the lake/sea breezes to produce severe weather. A total of four cases were analyzed in the pure category, while a half a dozen were investigated in the mixed one.

A flow chart developed by Wilson (2008) (Fig. 16) and subsequent threat charts/checklists classify cases based on thresholds of meteorological parameters that include: 1000-500 hPa thickness values, thermal difference between the water and near shore temperatures in the late morning, precipitable water values, boundary layer conditions, synoptic characteristics and stability parameters. Pure cases such as 9 August 2001 feature: 1) a strong ridge axis at the surface or aloft, 2) surface temperatures (dewpoints) of at least 30°C (20°C) in the afternoon, and 3) SBCAPE values of at least 1500 J kg⁻¹ from the nearest environmental sounding at 1200 UTC before the event. The mixed case sample (19 April 2002) involves slightly different criteria which feature: 1) a trough at the surface or aloft, 2) surface temperatures (dewpoints) ranging from 20 to 30°C (10 to 20°C), 3) cyclonic vorticity increasing with height in the vicinity of the severe convection. All the cases, aside from the one null case in the dataset,

stressed the importance of the interaction of multiple synoptic and mesoscale boundary intersections. The boundary intersections were initiation areas due to convergence and lift for deep, severe convection.

Threat chart checklists were developed for potential lake or sea breeze severe weather based on the two categories. There are ten criteria threat elements (Tables A and B for each case). A point is scored for each severe threat chart element that verifies. The threat or risk of severe weather with the lake or sea breeze boundary is high, when the tally is close to 10. A score of less than 4 yields little risk. A score of 5-6 indicates a slight risk. A moderate risk of severe convection occurs with a 7-8 score. A score of 9-10 is a high risk. These tallies from the checklist are based on a small sample size and exhibit a risk level, not a probabilistic chance of severe weather in these cases. The two cases from 9 August 2001 and 19 April 2002 scored high on the threat chart with tallies of 8 and 7, which would help operational forecasters on the level of risk and the quantity of severe weather reports that may occur in these situations.

The flow chart and threat assessment checklists are intended for future application in forecasting lake or sea breeze convection by the operational forecast community. It is hoped a more refined set of applications can be utilized in the future with a larger sample size where statistical significance testing can be done.

6. Acknowledgements

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7. References

- King, P. W. S., M. Leduc, D. M. L. Sills, N. R. Donaldson, D. R. Hudak, P. I. Joe, B. P. Murphy, 2003: Lake breezes in Southern Ontario and their relation to tornado climatology. *Wea. and Forecasting*, **18**, 795-807.
- Kristovich, D. A., R. E. LaPlante, N. F. Laird, and W. Kubina, 2003: Are thunderstorms that form along lake breezes more intense? Preprints, *Midwest Regional Conf. on Extreme and Hazardous Weather*, Central IL, Amer. Meteor. Soc.
- NOAA, 2003. *Storm Data*. Vol.45, National Climatic Data Center. [Available from National Climatic Data Center, Federal Building, 151 Patton Ave., Asheville, NC 28801.]
- Sills, D., P. Taylor, P. King, W. Hocking, and I. Nichols., 2002: ELBOW 2001 - Studying the relationship between lake breezes and severe weather: project overview and preliminary results. Preprints, *21st Conf. on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., 611-614.
- Thompson, R.L., R. Edwards, J.A. Hart, K.L. Elmore, and P.M. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243-1261.
- Wilson, P. H., 2008: Warm-Season Lake-/Sea-Breeze Severe Weather in the Northeast. Master Thesis completed at the University at Albany, State University of New York.
- Wolf, R. A., 2004: Tornadogenesis and the role of a lake breeze boundary on 14 June 2003 in northwest Illinois. Preprints, *22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., 14.6.

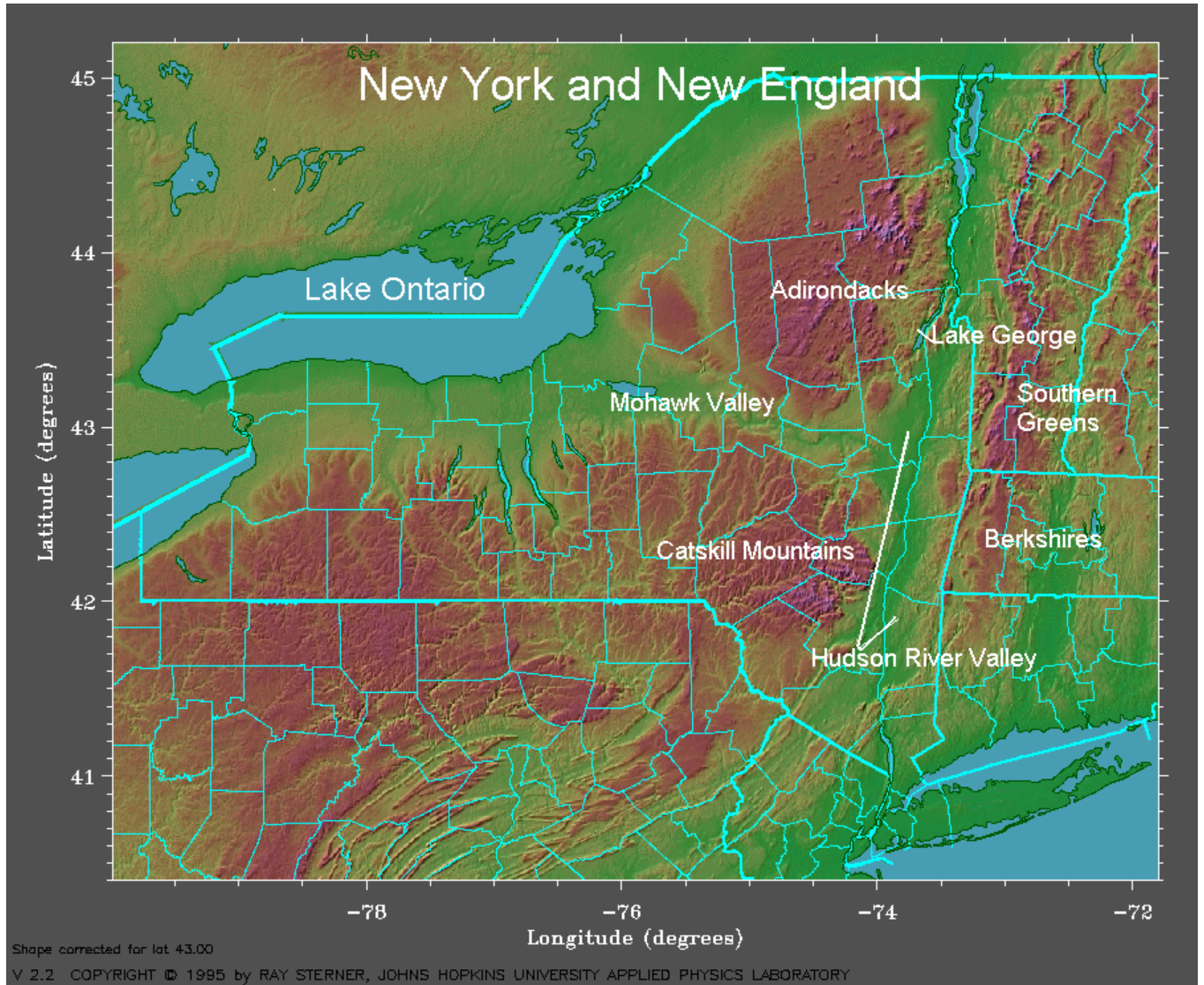


Figure 1: Topography map of NY and western New England

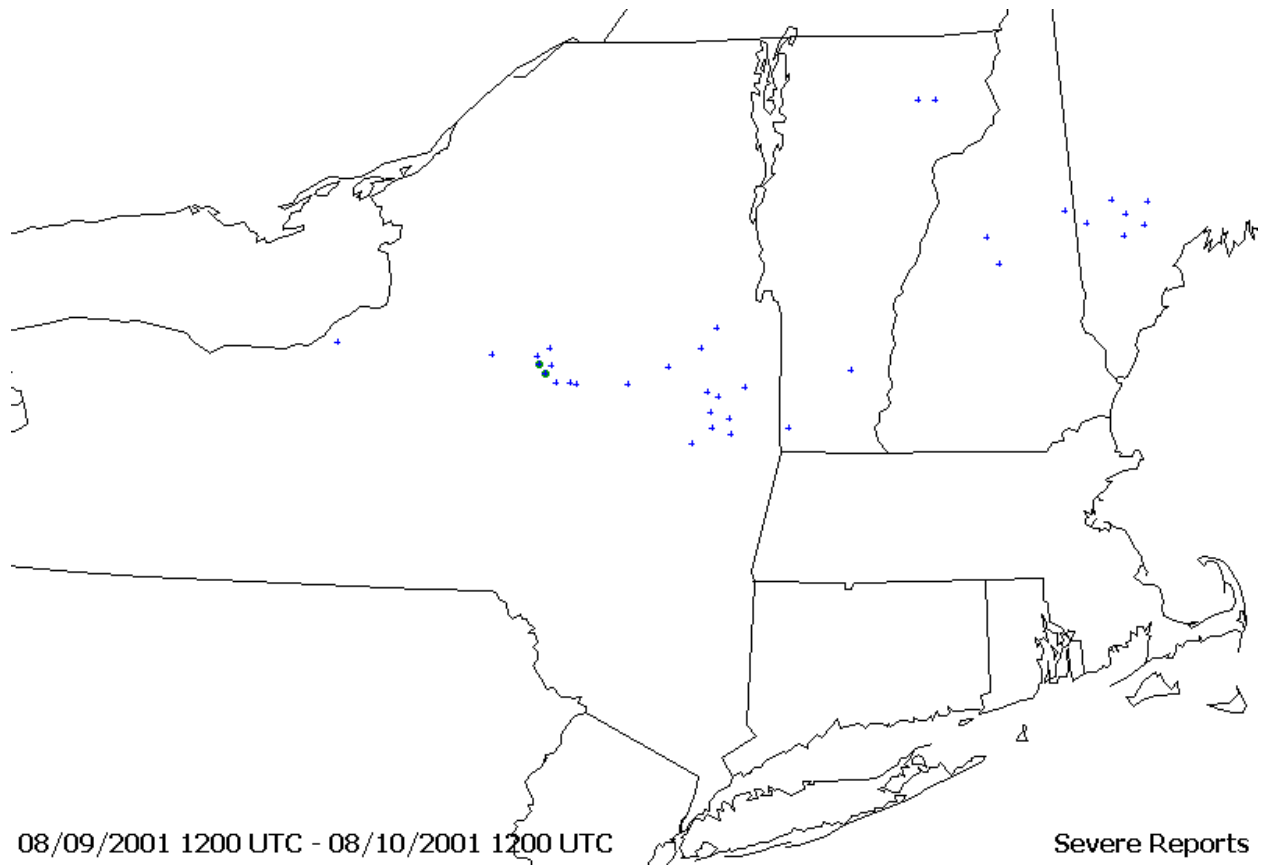


Figure 2: Storm Reports from SPC 9 August 2001 (NCDC, 2003)

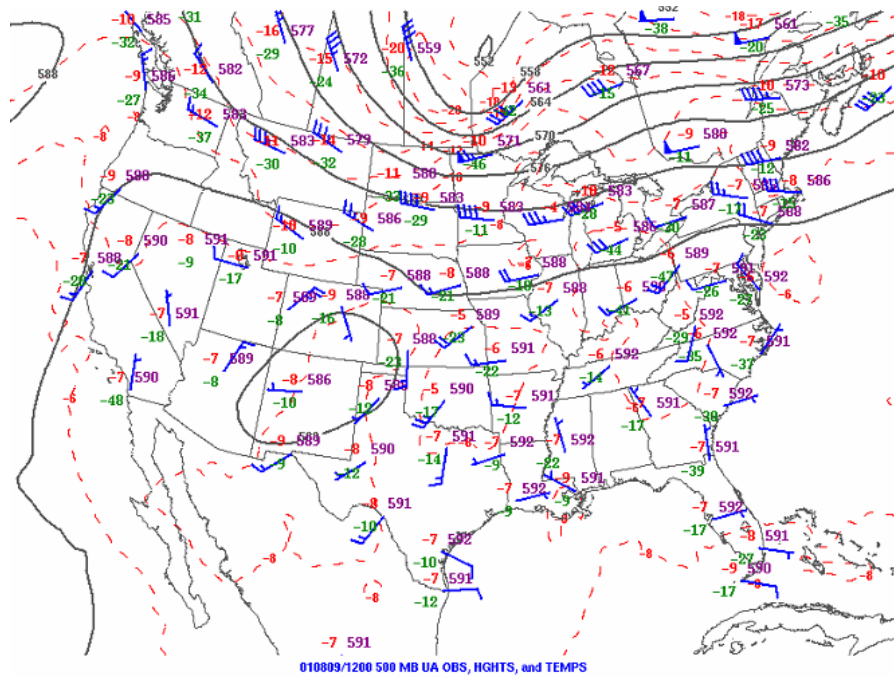


Figure 3: 500 hPa height (dam, solid), temperatures (°C, dashed red), winds (knots) and dewpoint depressions from RAOBs (green), valid 1200 UTC 9 August 2001.

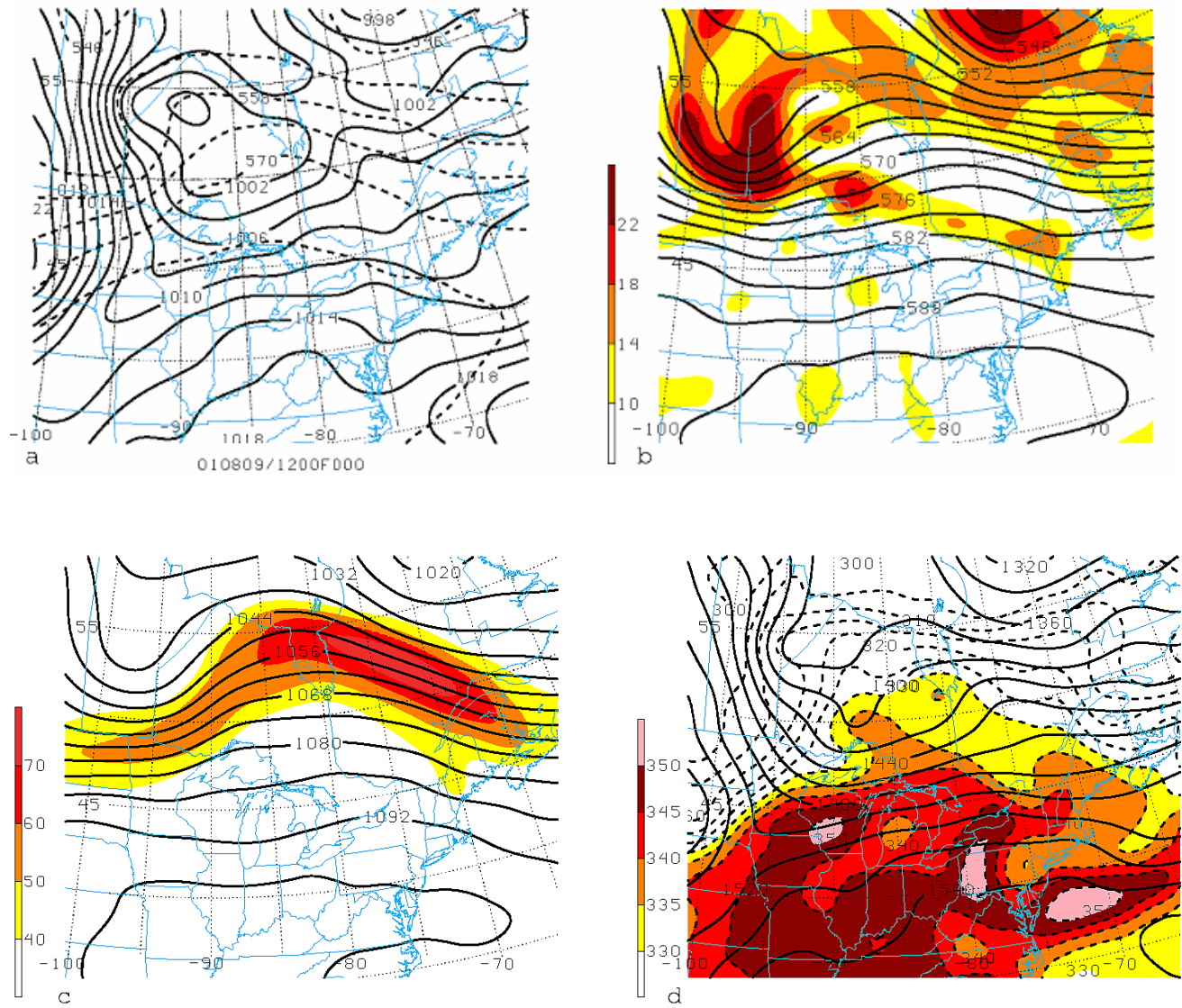


Fig. 4: a) 1200 UTC 9 August 2001 Eta a). MSLP (hPa, solid line) and 1000-500 hPa thickness (dam, dashed) b). 500 hPa heights (solid, dam) and Absolute Vorticity ($10 \times 10^{-5} \text{ s}^{-1}$, shaded) c). 250 hPa heights (dam, solid lines) and Isotachs (m s^{-1} , shaded) d). 850 hPa (dam, solid lines) and θ -e (every 5 K, shaded)

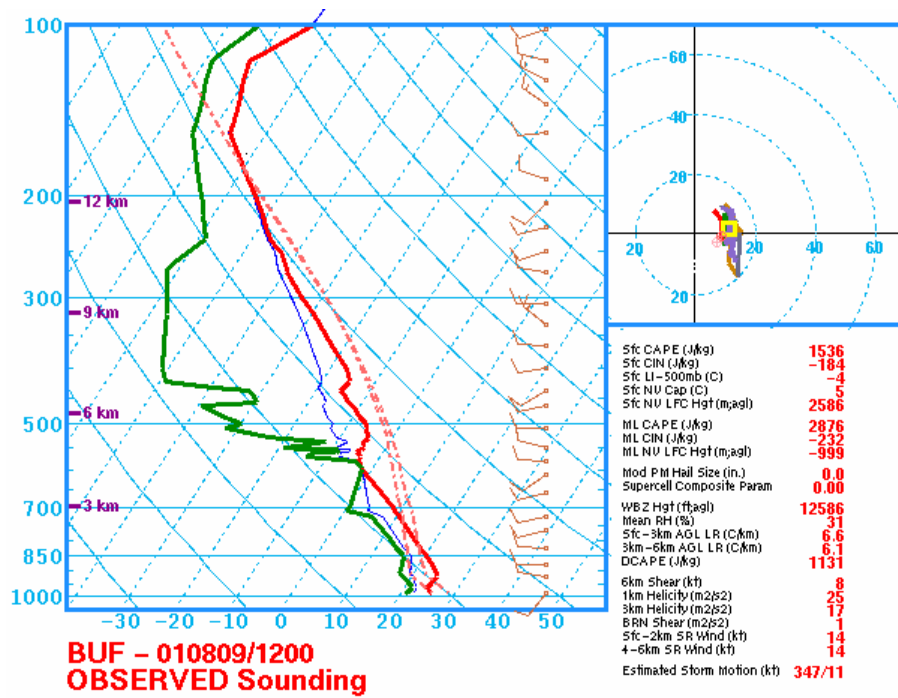


Figure 5: 1200 UTC 9 August 2001 Buffalo Sounding (<http://www.spc.noaa.gov>).

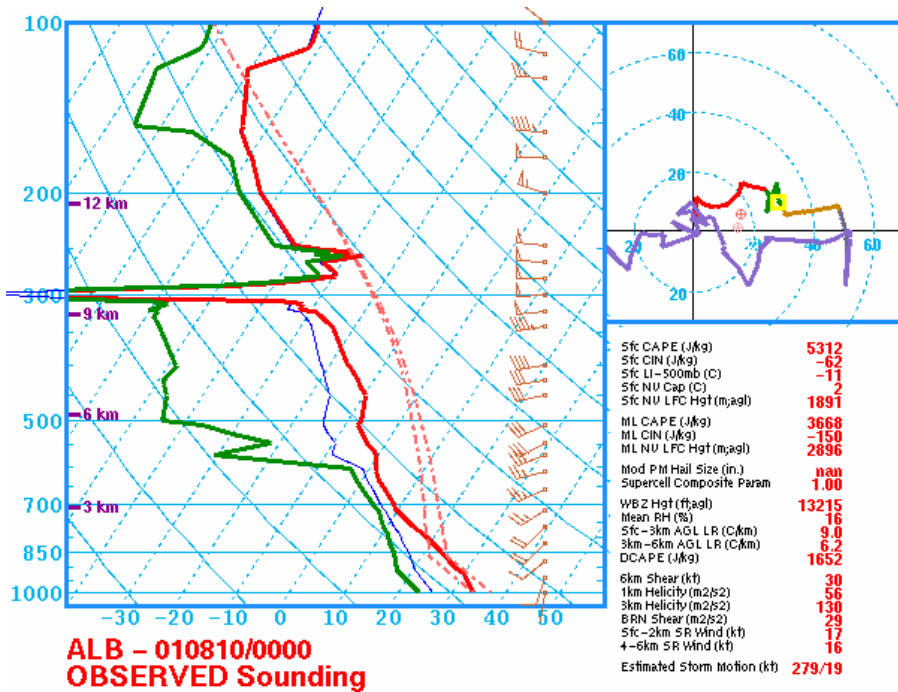


Figure 6: 0000 UTC 10 August 2001 Albany Sounding (<http://www.spc.noaa.gov>).

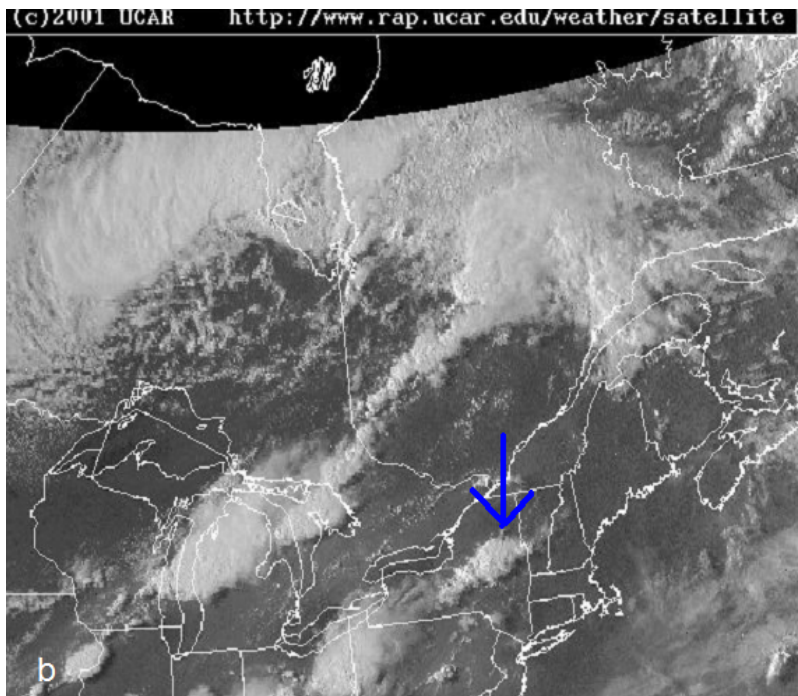
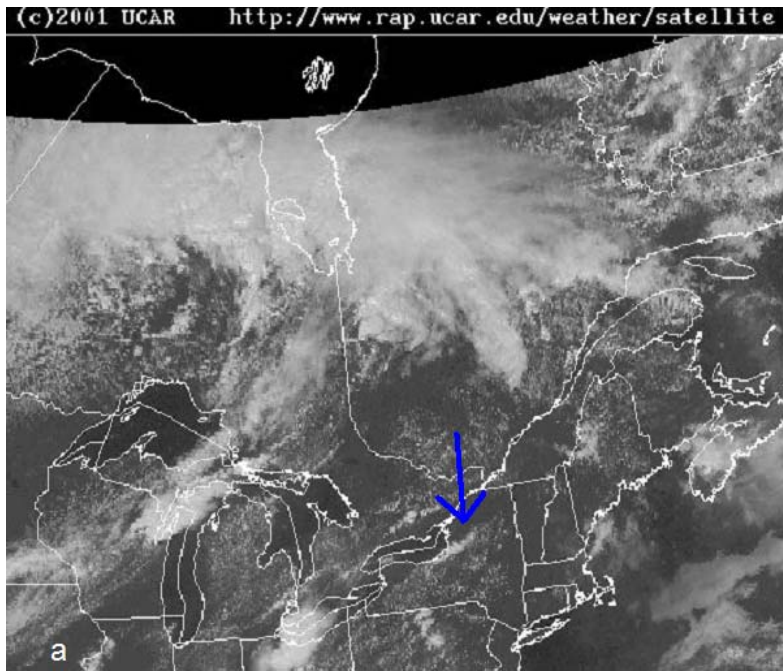


Figure 7: a). 1845 UTC 9 August 2001 Visible Satellite picture b). 2145 UTC 9 August 2001 Visible Satellite picture (The blue arrow indicates a lake breeze that helped trigger an MCS.

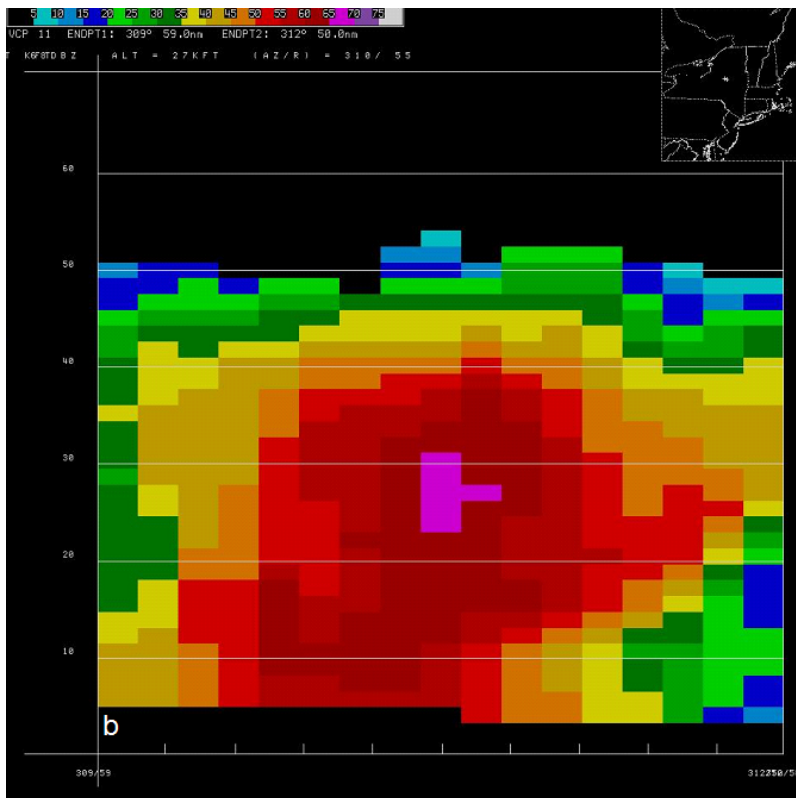
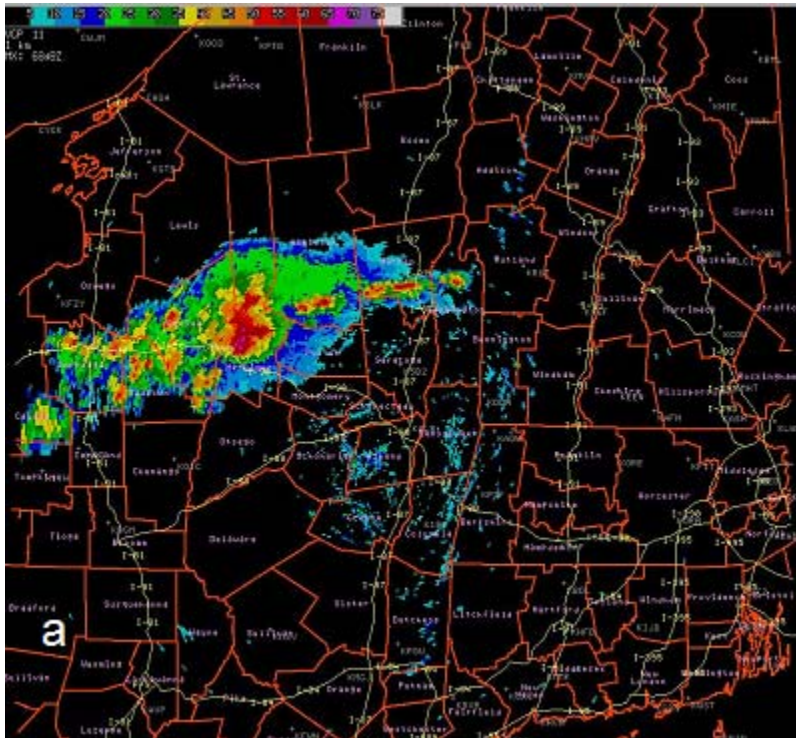


Fig. 8: a). 2156 UTC 9 August 2001 KENX Composite Reflectivity (dBZ) b). 2156 UTC KENX Reflectivity Cross-Section through southern Herkimer County Storm (65+ dBZ core between 25 kft and 31 kft).

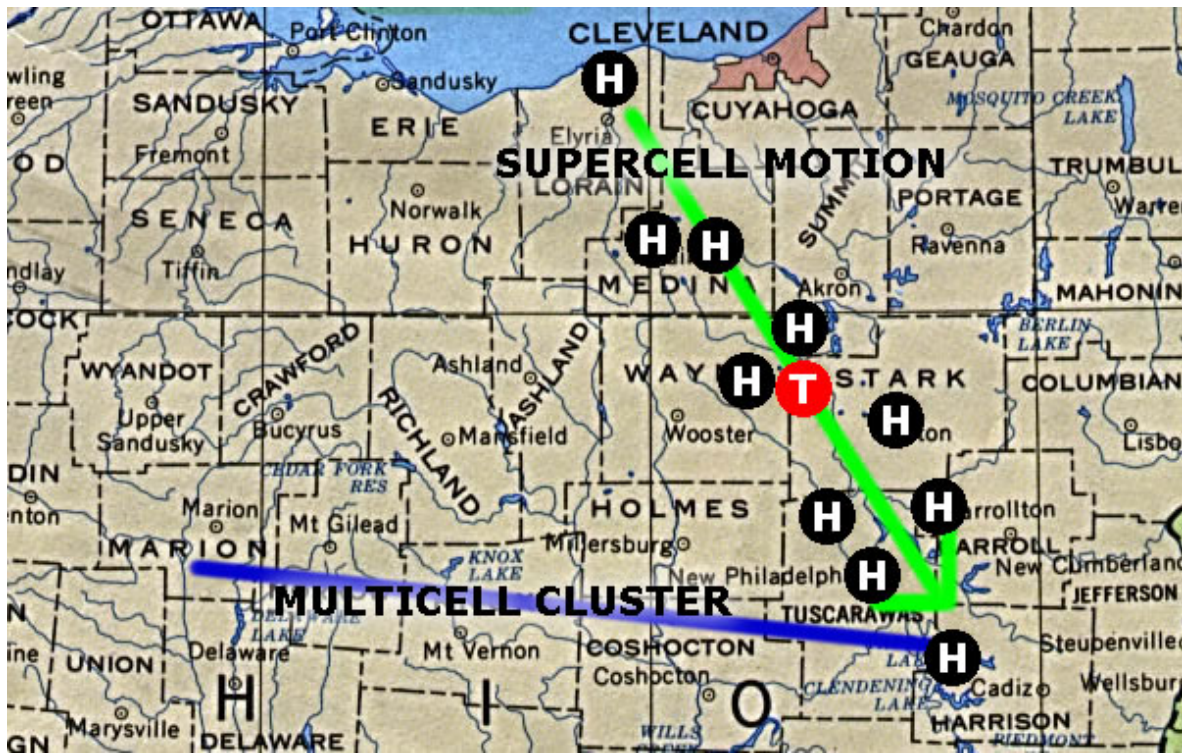


Fig 9: Severe weather reports from a super cell and multicell cluster that fired from a lake breeze 19 April 2002.

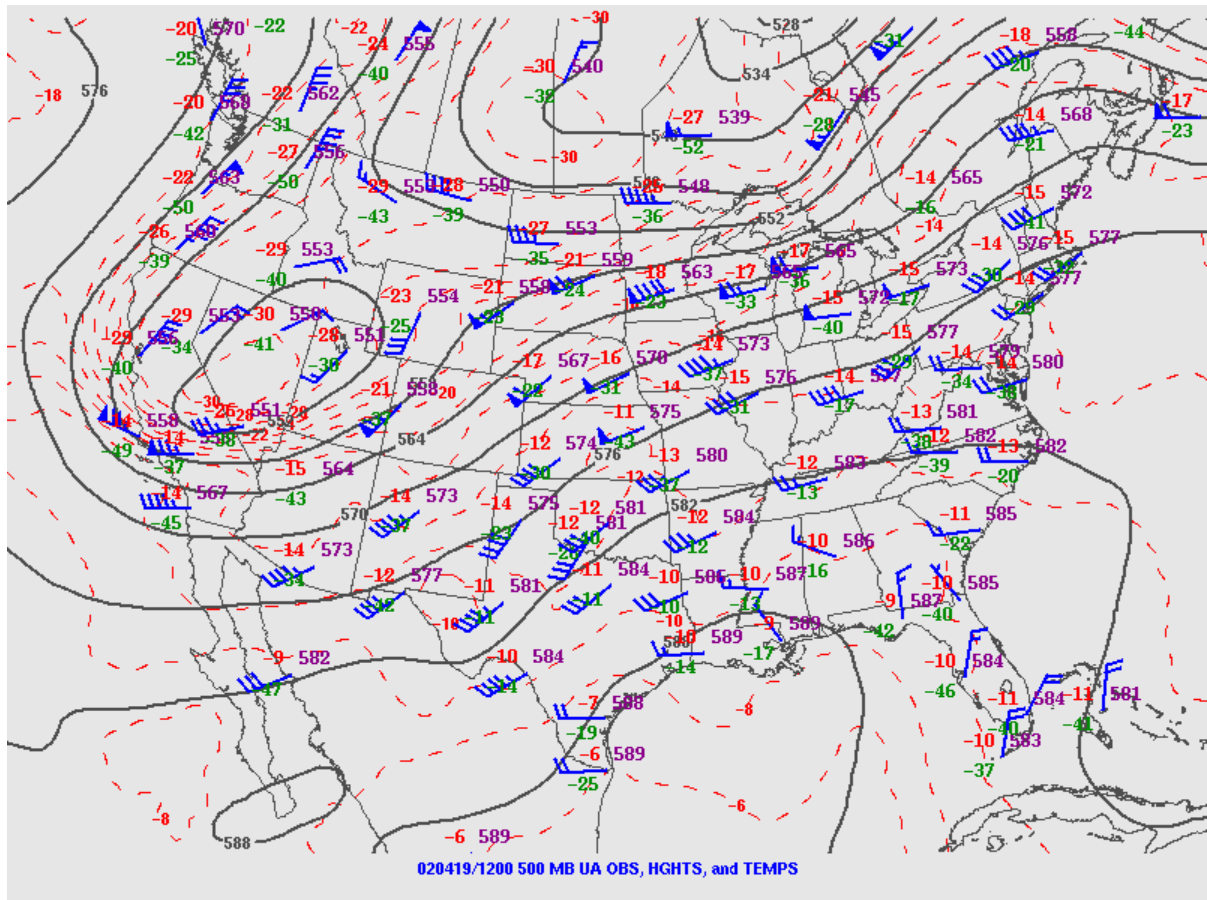


Figure 10: 500 hPa height (dam, solid), temperatures ($^{\circ}\text{C}$, dashed red), winds (knots) and dewpoint depressions from RAOBs (green), valid 1200 UTC 19 April 2002.

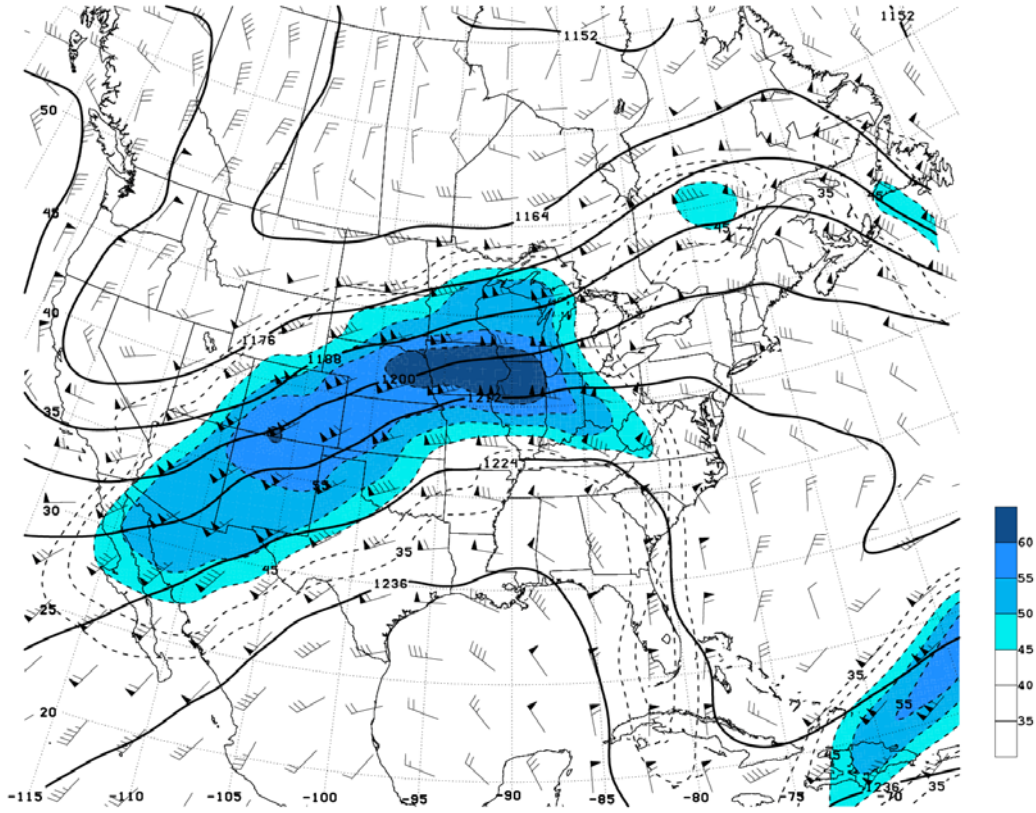


Figure 11: 200 hPa height (dam, solid), isotachs (dashed, shaded $> 45 \text{ m s}^{-1}$) and wind barbs (m s^{-1}) valid 1200 UTC 19 April 2002 from ETA initial analysis.

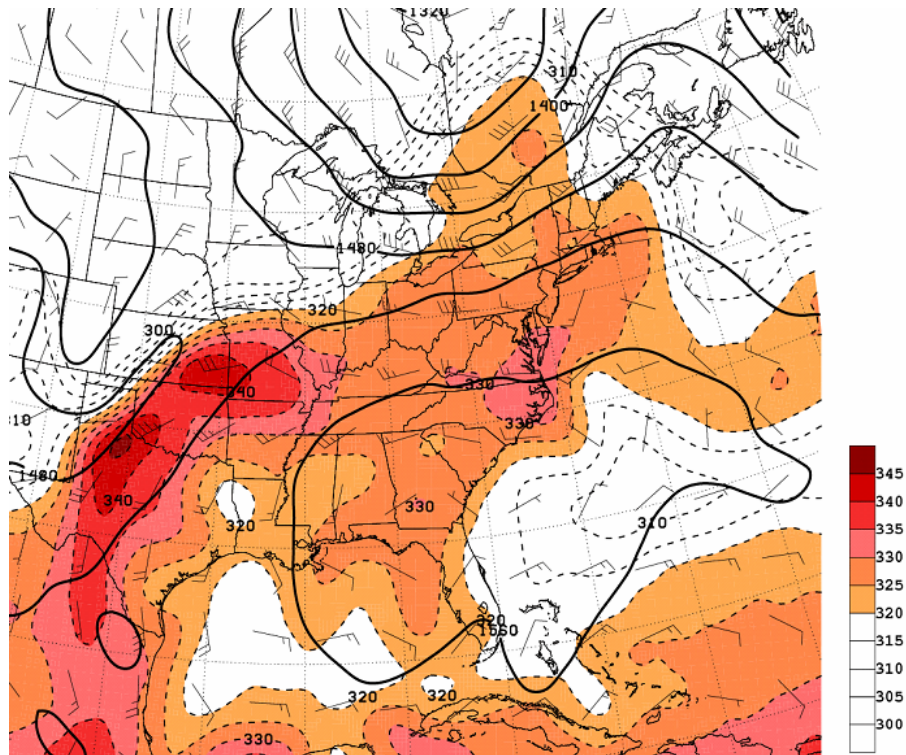
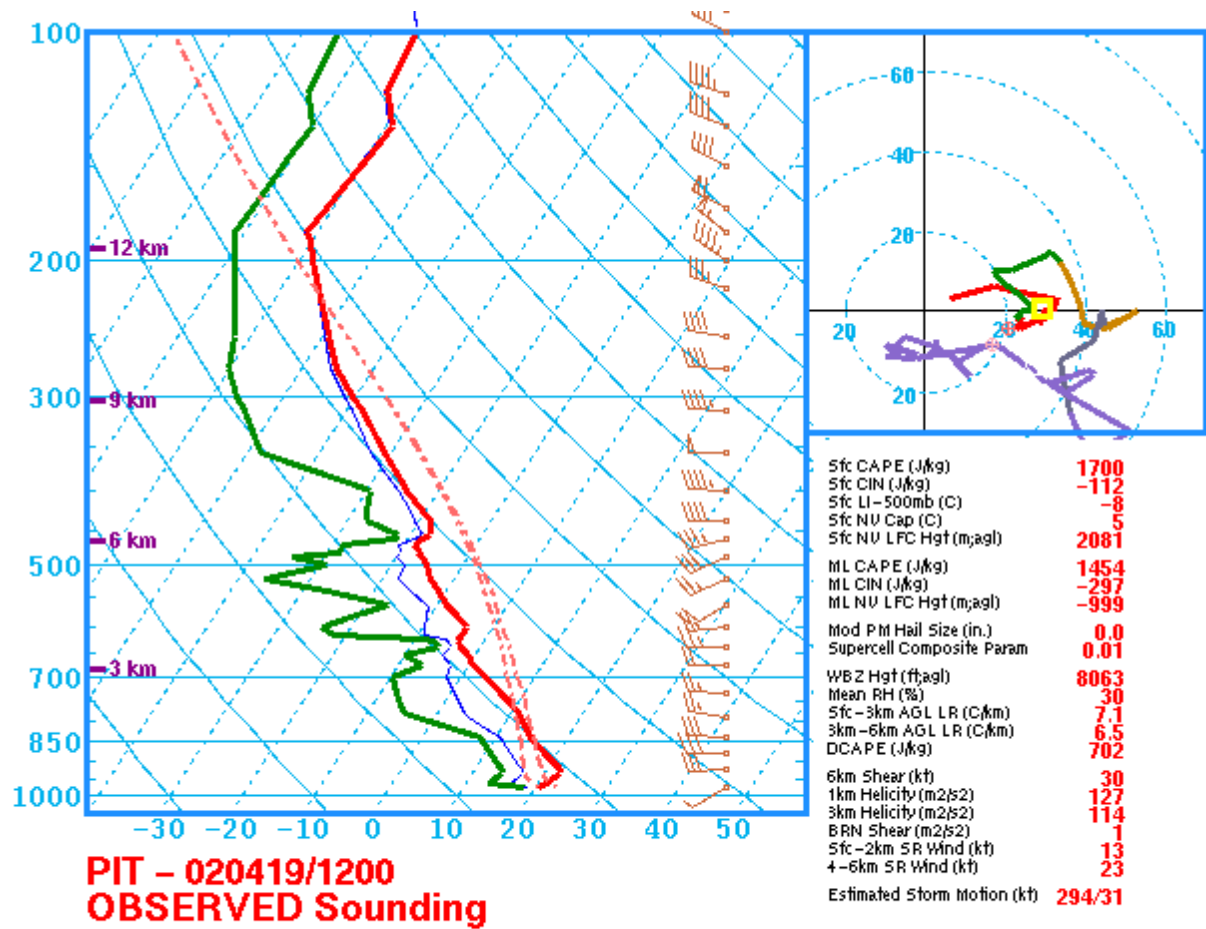


Figure 12: 1200 UTC 19 April 2002 ETA 850 hPa Heights (m), Wind (kts) and Theta-e (K)



NWS/NCEP/SPC

Figure 13: 1200UTC 19 April 2002 Pittsburgh sounding (<http://www.spc.noaa.gov>).

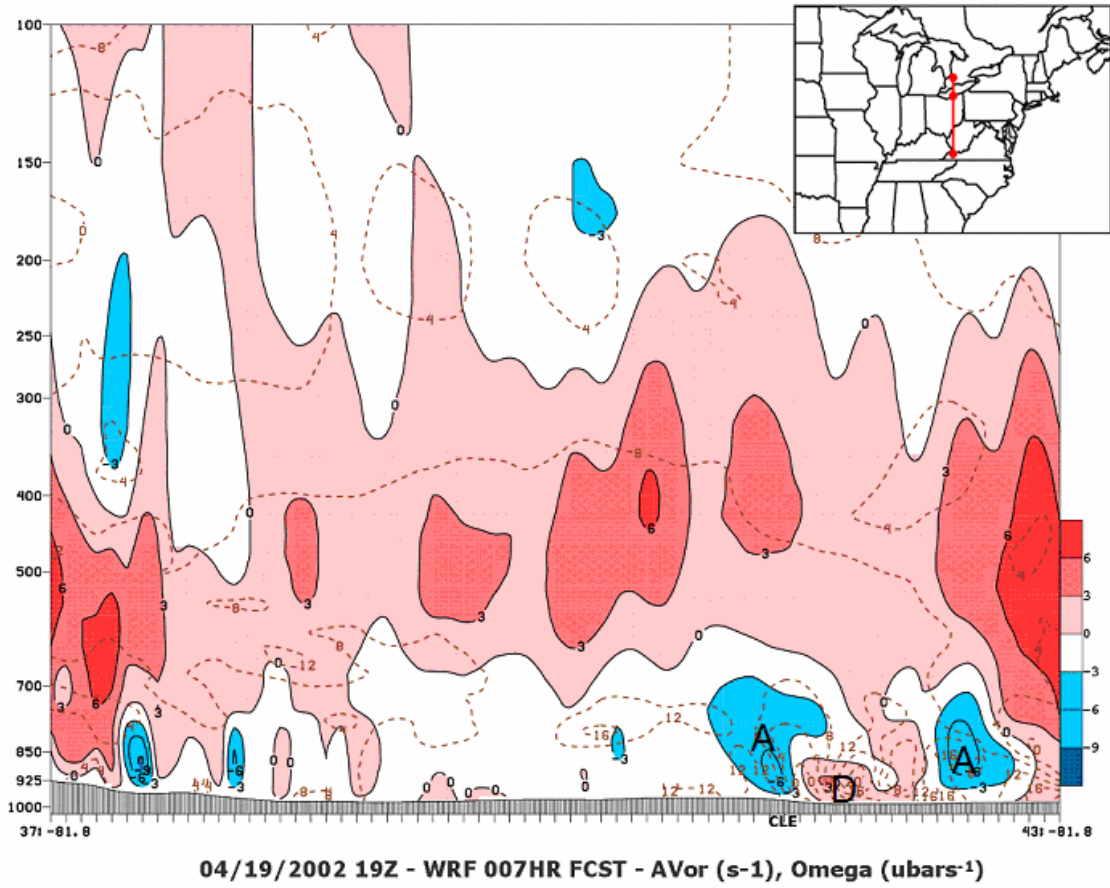


Figure 14: 1200 UTC 19 April 2002 2 km – WRF F1900 UTC cross-section of absolute vorticity and omega (ascent cool colors “A”, warm colors descent “D”) show sea breeze circulation near CLE.

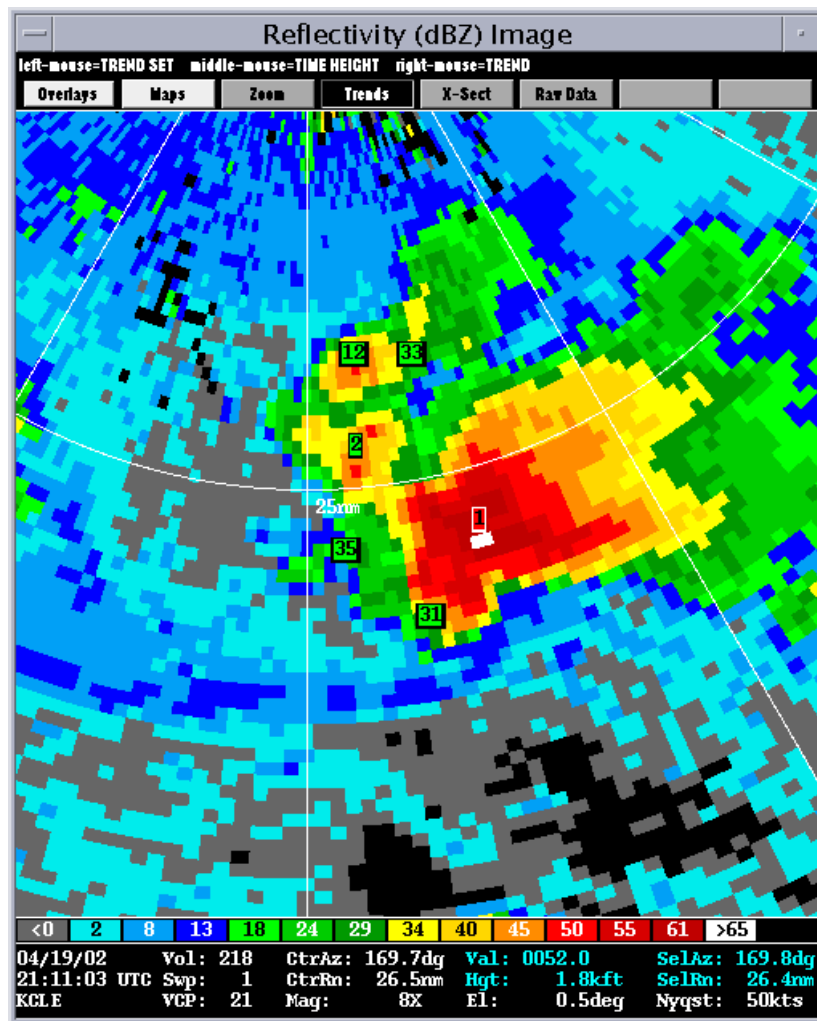


Figure 15: 2111 UTC 0.5° KCLE WATADs Base Reflectivity image with a hook echo southeast of the RDA.

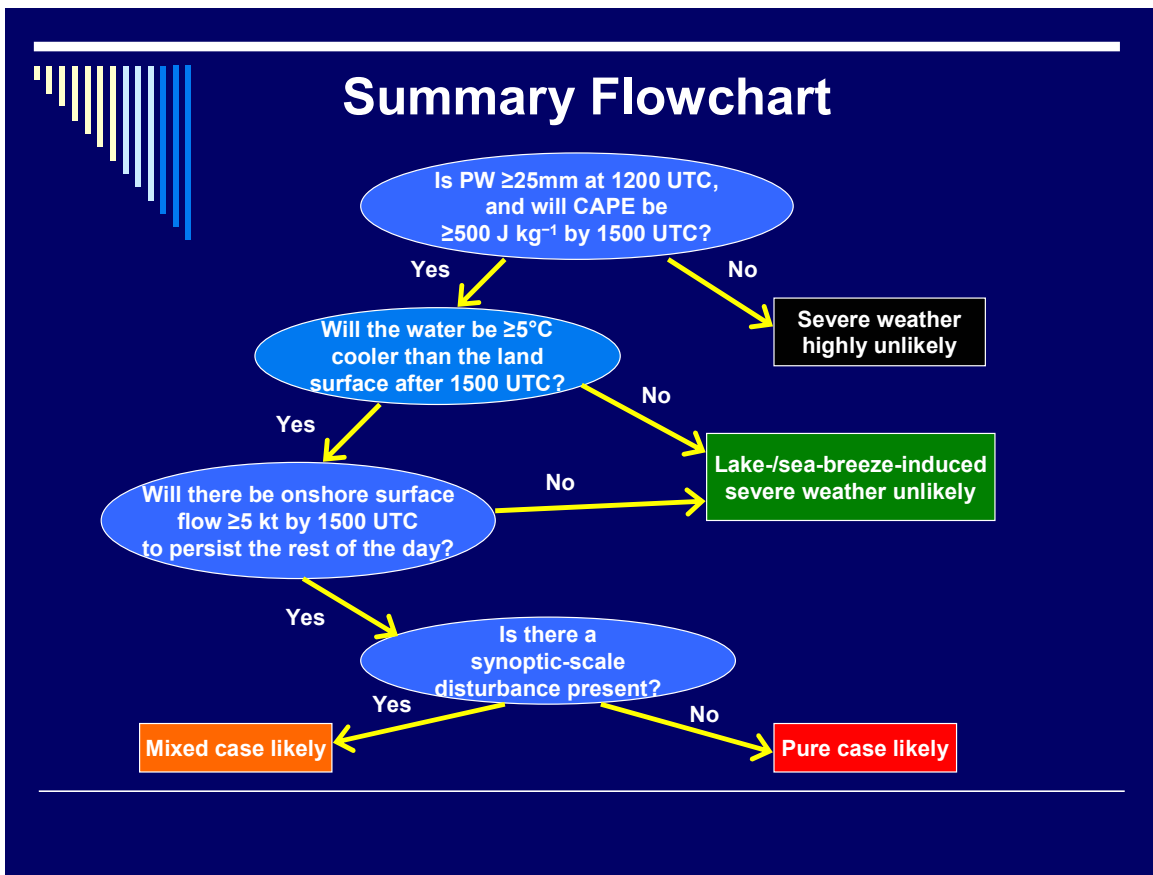


Figure 16: A summary lake/sea breeze flow chart for pure and mixed cases (Wilson, 2008).

Atmospheric Condition and Severe Weather	9 Aug 2001
No synoptic-scale disturbance present during daylight hours	Yes
1000–500 hPa thickness ≥ 570 dam during daylight hours	Yes
PW ≥ 40 mm from 1200 UTC proximity sounding	Yes
CAPE ≥ 1500 J kg ⁻¹ from 1200 UTC proximity sounding	Yes
LFC ≥ 800 hPa from 1200 UTC proximity sounding	No
CIN ≥ -125 J kg ⁻¹ from 1200 UTC proximity sounding	No
Observed surface temperature $\geq 30^\circ\text{C}$ in the afternoon	Yes
Observed surface dewpoint $\geq 20^\circ\text{C}$ in the afternoon	Yes
Observed land/water temperature difference $\geq 5^\circ\text{C}$ in the afternoon	Yes
Analyzed 1000–700 hPa onshore wind shear ≥ 15 kt in the afternoon	Yes

Table A.

Atmospheric Condition and Severe Weather	19 Apr 2002
Synoptic-scale disturbance present during daylight hours	Yes
1000–500 hPa thickness ≥ 555 dam during daylight hours	Yes
PW ≥ 25 mm from 1200 UTC proximity sounding	No
LFC ≥ 750 hPa from 1200 UTC proximity sounding	No
CIN ≥ -100 J kg ⁻¹ from 1200 UTC proximity sounding	No
Analyzed 500 hPa ζ present in the afternoon	Yes
Observed surface temperature $\geq 20^\circ\text{C}$ in the afternoon	Yes
Observed surface dewpoint $\geq 10^\circ\text{C}$ in the afternoon	Yes
Observed land/water temp. difference $\geq 5^\circ\text{C}$ in the afternoon	Yes
Analyzed 1000–700 hPa onsh. wind shear ≥ 20 kt in the afternoon	Yes

Table B.

Table A: 9 August 2001 Checklist results where 36 severe reports occurred (34 wind and 2 hail)

Table B: 19 April 2002 Checklist results where 31 severe reports occurred (3 wind, 27 hail and 1 F0 tornado)