SYNOPTIC CONDITIONS FAVORABLE FOR THE FORMATION OF THE 15 JULY 1995 SOUTHEASTERN CANADA/NORTHEASTERN U.S. DERECHO EVENT

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Abstract

On 15 July 1995, a derecho-producing mesoscale convective system inflicted considerable damage through southeastern Canada and the northeastern U.S. The synoptic-scale environment that precluded and persisted during this event is examined using surface and upper-air observations, satellite imagery and numerical model data. Evidence suggests that low-level moisture inflow and forcing were major factors in initiating and sustaining this progressive warm season derecho event. Favorable upper-level dynamics produced by jet streak induced circulations were also found over the region. Products from the Eta model run initialized 12 hours prior to the event were used in the study to fill in between the 0000 UTC and 1200 UTC upper-air sounding times.

Manipulation of these data sets was accomplished using GEMPAK 5.2.1. Calculation of 850 hPa moisture transport vectors and frontogenesis were found to be particularly useful in determining the derecho producing mesoscale convective system's genesis and propagation regions. Future investigations of these systems should employ these techniques in order to assess their forecast applications.

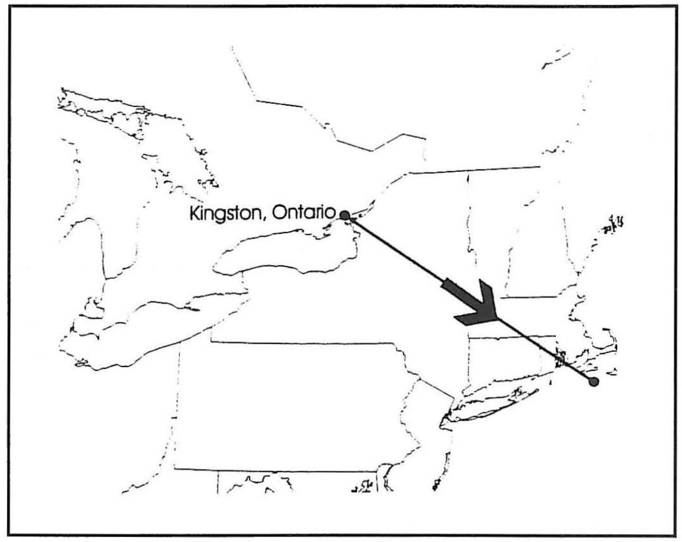

Fig. 1. Approximate track of the DMCS cloud shield on 15 July 1995.

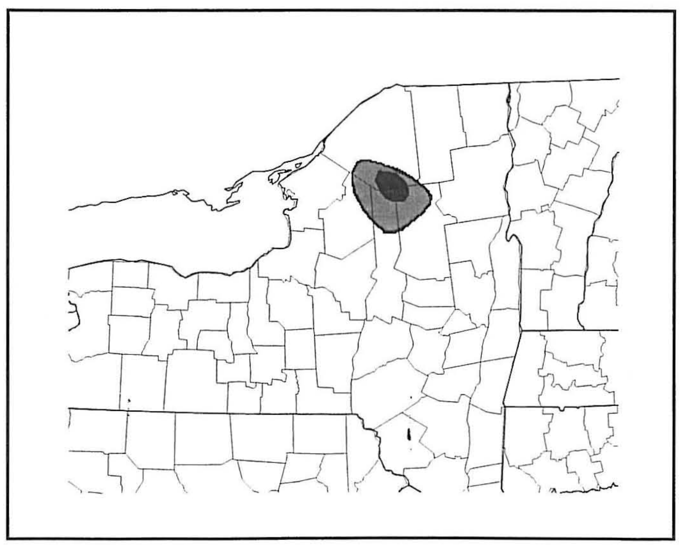

Fig. 2. Tree damage produced by the 15 July DMCS in the Five Points Wilderness area of Adirondack Park. Light shading indicates moderate tree damage while dark shading denotes an area where 60 to 90 percent of the trees were either damaged or destroyed, (after GIS Section, Division of Land Forests, 1995).

1. Introduction

In the early morning hours of 15 July 1995, a derecho-producing mesoscale convective system (hereafter, DMCS) moved from southern Canada through the northeastern United States (Fig. 1). Widespread wind damage was reported throughout the Northeast. The Adirondack mountain region of northern New York was especially hard hit (Fig. 2). Five fatalities were reported, as a result of fallen trees. It has been estimated that a million acres of forest were affected by the derecho. Although the total number of trees blown down is not known, conservative estimates are in the millions.

The DMCS organized from a cluster of thunderstorms over Lake Superior at approximately 0000 UTC 15 July 1995 (Fig. 3). From this point on, the mesoscale convective system (MCS) moved eastward around the north side of an expansive anticyclone anchored over the Ohio Valley. The location and induced flow around this high pressure ridge produced a low-level environment conducive to MCS formation. At approximately 0730 UTC 15 July, near Kingston, Ontario, the MCS intensified and began producing wind damage. Moving at nearly 36 m s^{-1}, the DMCS struck the Adirondacks at 0900 UTC. By 1230 UTC it had reached Providence, Rhode Island and began dissipating as it interacted with the marine layer. At the airport in Watertown, New York, winds of 39 m s^{-1} were recorded before the anemometer broke. Winds over 34 m s^{-1} were common throughout the region, with some gusts reported over 45 m s^{-1}.

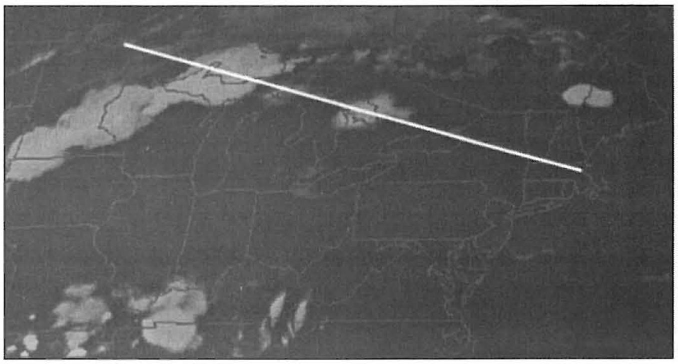

Fig. 3. GOES-8 infrared image, 0015 UTC 15 July 1995. The MCS that eventually produced the derecho is located over Lake Superior. White line on satellite imagery (black line on maps) in this and other figures, from International Falls, MN to Boston, MA, indicates the location for vertical cross-sections.

Watertown, Albany, and portions of western Massachusetts were especially hard hit by the derecho.

Although this was a "classic" warm season progressive derecho (Johns and Hirt 1987), formation and sustainment of the system in southeastern Canada and the northeastern United States was unusual. The synoptic-scale environment in place over the region produced the necessary conditions for the formation of severe, long-lived, MCSs.

2. Background

Refinements to Gustavus Hinrichs definition of a derecho have evolved after numerous investigations of these events (Hinrichs 1888; Howard et al. 1985; Johns and Hirt 1985; 1987; Johns et al. 1990). A derecho is a severe, straight-line wind event produced by an extratropical MCS (Johns and Hirt 1987). This definition includes any family of downburst clusters with temporal and spatial continuity and a major axis of at least 400 km (Fujita and Wakimoto 1981; Johns and Hirt 1987). A closer examination reveals two types of derechos: serial and progressive (Johns and Hirt 1987). Although observational evidence suggests distinct environments and mechanisms producing either serial or progressive events, there are documented cases exhibiting characteristics of both (Duke and Rogash 1992).

The southeastern Canada/northeastern United States derecho event falls under the warm season, progressive derecho category. Progressive derechos form in conjunction with relatively weak synoptic features and show the characteristics of both linear and nonlinear types of MCSs (Johns and Hirt 1987). Evidence suggests that progressive derechos form mainly in the late spring and summer when convective instability is the greatest.

Observational studies of DMCSs indicate that the common radar signature of the system is the bow echo (Przybylinski and Gery 1983; Przybylinski and DeCaire 1985; Johns 1993; Przybylinski 1995; Cooper and Bentley 1996). In a study of 20 derecho cases, four echo types were observed using conventional radars (Przybylinski and DeCaire 1985). The type I echo is a solid line of as many as three concave shaped echoes 150 to 250 km in length. The southeastern Canada/northeastern United States DMCS was of the type I echo configuration as seen on the Albany, NY (ENX) Doppler radar (Fig. 4).

Synoptic-scale investigations into DMCS conducive environments indicate an interesting correlation. In a four-year study of derechos, a derecho corridor was found that extended from southern Minnesota to northern Ohio (Johns and Hirt 1987). Concentrations of severe convective wind gusts (> 25 m s^{-1}) and northwest flow severe weather outbreaks are oriented parallel to this derecho axis (Johns and Hirt 1987). Evidence suggests that DMCSs favor northwest flow environments (Johns 1984; Johns and Hirt 1987). As the MCS moved over the ridge axis in the early morning of 15 July, it encountered a northwest flow environment.

Numerical investigations into the structure of a DMCS reveal unique dynamic characteristics. Simulations suggest that evaporative cooling, melting of precipitation and downward transport of cool mid-level air through momentum and precipitation drag initiates the main downdraft and forms a cold pool below the system (Knupp and Cotton 1985; Schmidt 1991). The cold pool, interacting with environmental wind shear produces a long-lived updraft (Rotunno et al. 1988). In time, a buoyancy gradient and horizontal vorticity, both produced by cold pool and updraft interaction, form a mid-level rear-inflow jet (Weisman 1990; Weisman 1992). DMCSs evolve into quasi-steady state systems with self-sustaining internal structures. The cold pool and updraft interaction can cause the MCS to "pulse" in this quasi-steady state (Weisman 1993). During this phase of the mature DMCS, the cold pool circulation briefly overwhelms the ambient shear, resulting in several periods where the convective towers tilt upshear. However, the presence of strong (>20 m s^{-1}) low-level shear in the ambient environment can act to negate this process before it disorganizes the convective structure (Weisman 1993). Evidence suggests that during periods of upshear tilt, damaging downburst winds are most frequent (Przybylinski 1995). The production and sustainment of damaging surface winds, while thought to be largely a result of the

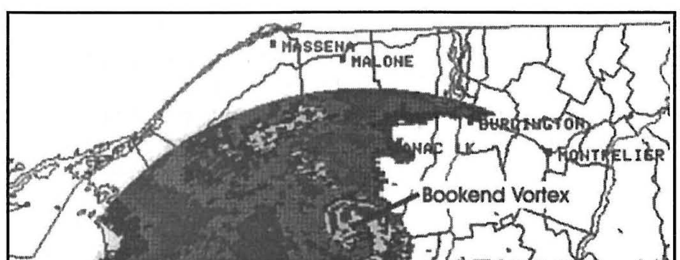

Fig. 4. Albany, NY (ENX) WSR-88D base reflectivity (0.5° elevation angle) image, 1000 UTC 15 July 1995.

cold pool, may also be caused by gravity waves (Schmidt and Cotton 1990; Schmidt 1991; Panya and Durran 1996).

Dynamic evolution of DMCSs form several detectable structures: the mesohigh, wake-low, bookend vortices, weak echo notches and bow echoes (Fujita 1981; Weisman 1993; Przybylinski 1995). These structures, evident through mesoanalysis and radar observations, assist the meteorologist in the analysis and prediction of the DMCS's internal dynamics and potential for severe weather.

This observational study will examine the synoptic environment that produced a DMCS on 15 July 1995. Surface and upper-air observations, satellite imagery and numerical model data were used to reconstruct the environment prior to and during the MCS formation.

3. Synoptic Environment

Much of the eastern third of the United States was smothered by a deadly heat wave from 10-16 July (Hughes and LeComte 1996). From 13-16 July, the heat migrated into the upper midwest and New England. La Crosse, Wisconsin reached 42°C (108°F) and Chicago's Midway Airport reached 41°C (106°F) on 13 July. On 14 July, temperatures in the upper 30's to low 40's (°C) extended from New England, west into the Great Lakes. Danbury, Connecticut reached an all-time high temperature of 41°C on 15 July (Hughes and LeComte 1996).

Accompanying the record heat was extreme boundary layer moisture. Dewpoint temperatures near 27°C (81°F) were common in the region during 10-16 July. This combined heat and moisture created extreme low-level instability (Fig. 5).

a. 0000 UTC 15 July 1995

Several regions of frontogenesis were located along the northern periphery of the major high pressure system (Fig. 6). Frontogenesis maxima illustrate areas of enhanced lift which produced thunderstorms along the thermal boundary (Fig. 3). Three processes are contained in the frontogenesis calculation: configuration of the horizontal flow, tilting of stable layers and differential heating. A confluent configuration of the horizontal flow at 850 hPa was likely the main contributor to the warm frontogenesis occurring in the upper Great Lakes. It has been documented (e.g., Maddox and Doswell 1982) that for situations in which mid-level vorticity patterns are weak, (i.e., warm season derecho patterns) the emphasis should be placed on examining low-level thermal advection fields for diagnosing upward vertical motion. A similar scenario had occurred the previous evening but the MCSs which developed failed to maintain intensity as they propagated east across the ridge axis. The ridge, however, was de-amplifying with time.

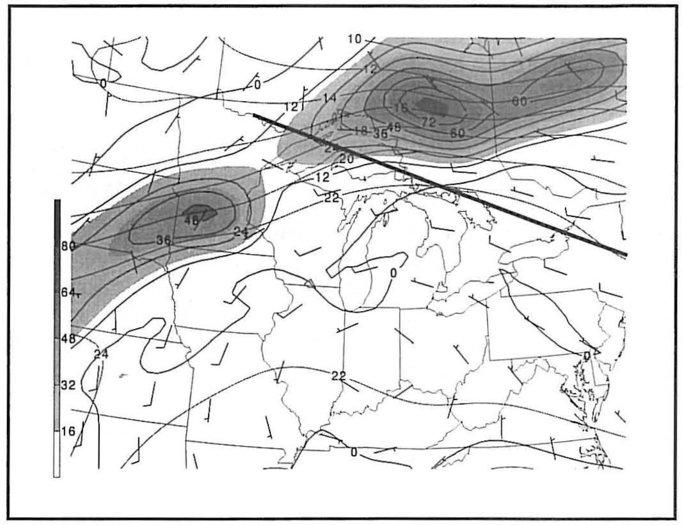

Fig. 6. 850 hPa Frontogenesis (x 10^{-2} K $100km^{-1}$ $3h^{-1}$, shaded), Isotherms (°C), and Winds (m s^{-1}) for 0000 UTC 15 July 1995.

Several features were diagnosed by examining the 850 hPa moisture transport, theta-E and heights (Fig. 7). Moisture transport vectors are calculated by multiplying the wind vector by the mixing ratio (scalar). The magnitude of this vector can then be plotted to show regions of high or low moisture inflow. A

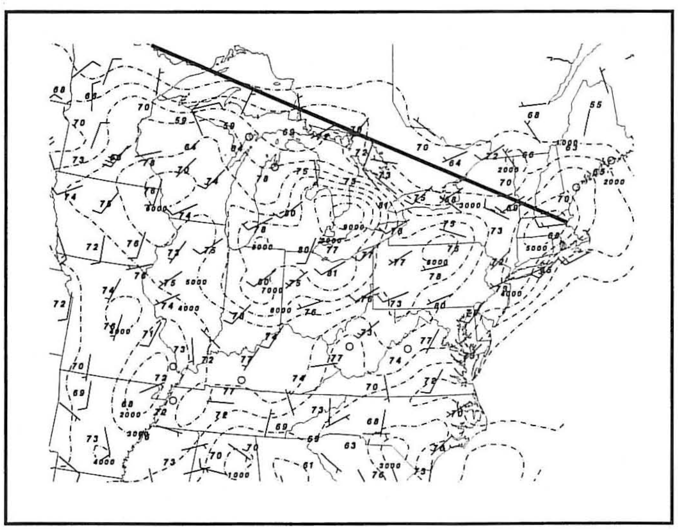

Fig. 5. Observed surface dewpoint temperatures (°F), winds and the Rapid Update Cycle (RUC) 0000 UTC 15 July 1995 initialization run (60 km resolution) convective available potential energy (CAPE, J kg^{-1}).

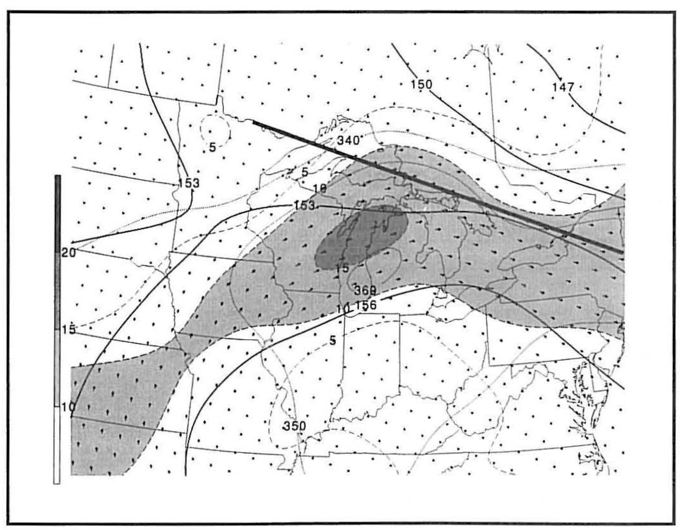

Fig. 7. 850 hPa Moisture Transport (vectors and magnitudes, g kg^{-1} m s^{-1}, dashed lines and shaded), Heights (dm) and Equivalent Potential Temperature (°K, dotted lines) for 0000 UTC 15 July 1995. Note: area of increasing moisture over Wisconsin and Michigan.

high magnitude of the moisture transport vector can be used to locate where the low-level jet (LLJ) and moisture axis coincide. The convection (which eventually evolved into the DMCS) was located north of an area of high moisture transport and in the height trough located over the Upper Peninsula of Michigan (Fig. 3). In this case, the moisture transport vector field illustrates the speed convergent nature of the northern edge of the LLJ and maximum moisture inflow over the upper Great Lakes (Fig. 7). The regions located in this convergence, northeast of the maximum, are especially favorable for MCS genesis. Warm air and moisture advection south of the MCS genesis region is well documented as being a prominent feature in DMCS formation (Knupp and Jorgensen 1985; Johns et al. 1990). Equivalent potential temperatures were over 350 K in this region, indicative of the extreme amount of heat and moisture contained in the low-levels of the atmosphere.

At 700 hPa, 12-20 m s^{-1} flow out of the northwest over the ridge axis was occurring from northern Michigan through the northeastern United States (Fig. 8). This provided a favorable shear environment for long-lived convection in the MCS genesis region. After examining the 700 hPa omega fields, it appears that synoptic-scale lifting mechanisms also played a role in this derecho situation (Figs. 9 and 10). Assuming the 10°C isotherm represents the edge of the elevated mixed layer (EML) inversion, it extended from Lake Superior through southern Maine (Fig. 8) (Lanicci and Warner 1991). The skew-T log P diagrams from Albany, New York and Maniwaki, Quebec support this location for the inversion edge (Figs. 11 and 12).

At 250 hPa, divergence in both the ambient and ageostrophic flow was occurring over Lake Superior (Fig. 13). This likely assisted in enhancing synoptic-scale lift over the DMCS genesis region as low-level convergence, moisture inflow and upper-level divergence acted in concert to initiate the DMCS.

As previously discussed, after an examination of upper-air data, several atmospheric elements were in place as of 0000 UTC 15 July 1995 that appeared conducive to sustaining severe thunderstorms. They were:

1) low-level warm air advection along the ridge boundary
2) low-level moisture inflow and convergence created by a LLJ
3) extreme low-level instability under the ridge

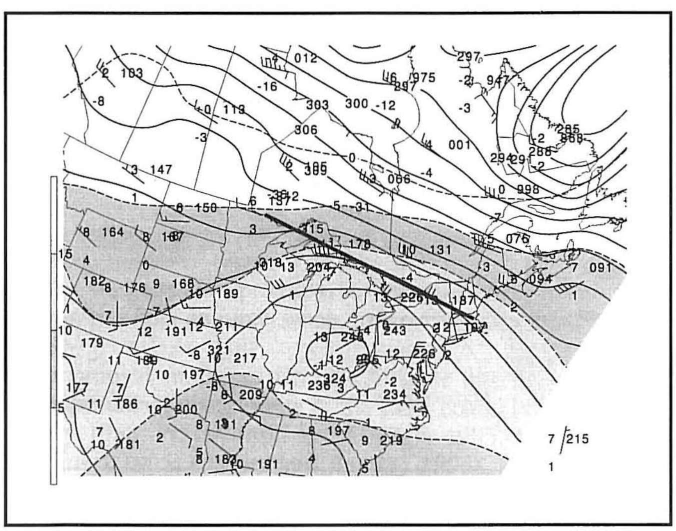

Fig. 8. 700 hPa Observations, Heights (dm) and Isotherms (°C, dashed lines and shaded) for 0000 UTC 15 July 1995.

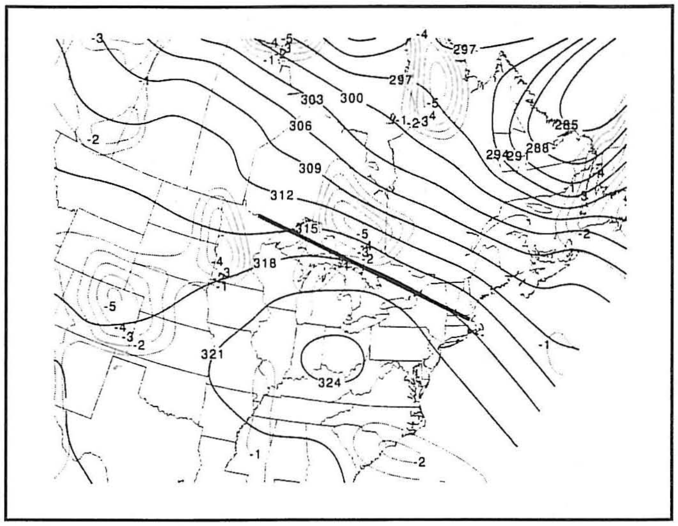

Fig. 9. 700 hPa Heights (dm) and Omega ($\times$ 10^{-3} μb s^{-1}, dotted lines) for 0000 UTC 15 July 1995. Note: the omega minimum located over Lake Superior and Southern Ontario.

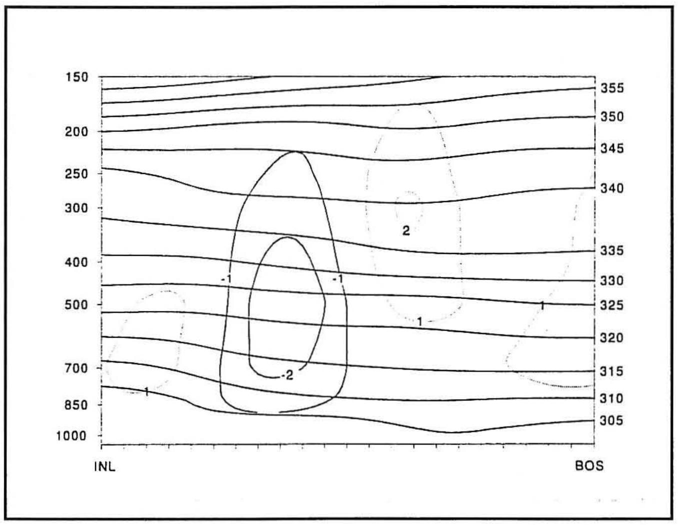

Fig. 10. Vertical cross-section of Omega ($\times$ 10^{-3} μb s^{-1}) and Isentropes (°K) along the DMCS track, from International Falls, MN (INL) to Boston, MA (BOS), for 0000 UTC 15 July 1995.

4) the presence of an elevated mixed layer inversion, capping widespread convection
5) moderate to strong northwest flow over southern Canada and New England which created a favorable shear profile
6) location under the right entrance region of an upper-level jet streak

b. 18-h Eta forecast valid for 0600 UTC 15 July 1995

Further examination of the event utilizes the 1200 UTC 14 July 1995 Eta forecast data for the period of the DMCS. This particular model run initialized and verified well with the state of the atmosphere at 1200 UTC 14 July and during the derecho event.

The DMCS, now in the northwest flow pattern on the east side of the ridge, began rapid intensification shortly after 0600

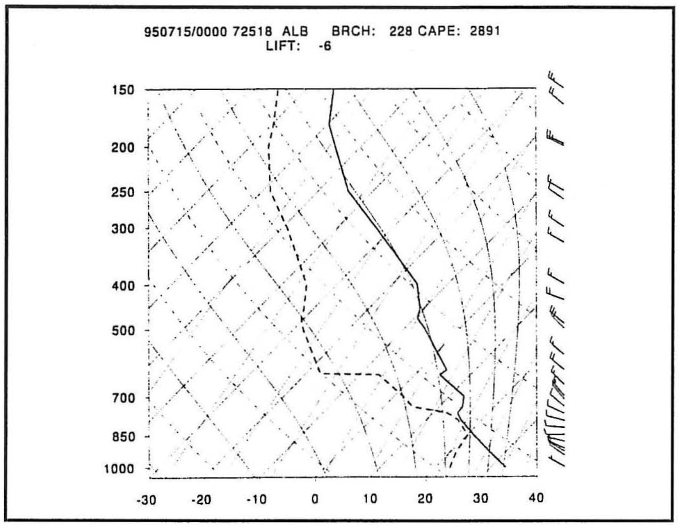

Fig. 11. Skew-T Log P diagram for Albany, NY, 0000 UTC 15 July 1995.

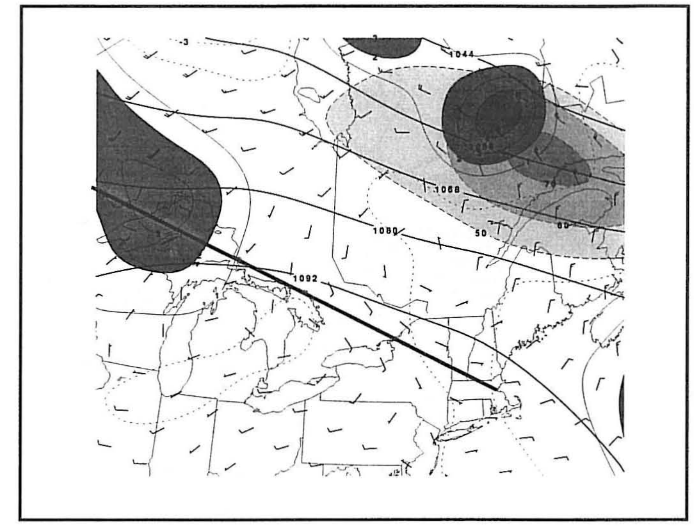

Fig. 13. 250 hPa Divergence (x 10^{-5} s^{-1}, dark shades), Heights (dm), Isotachs (m s^{-1}, light shades) and Ageostrophic Winds (m s^{-1}) for 0000 UTC 15 July 1995.

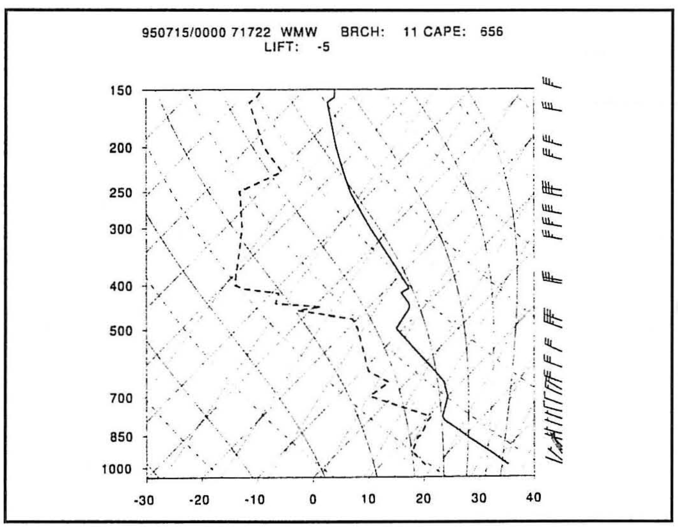

Fig. 12. Skew-T Log P diagram for Maniwaki, QB, 0000 UTC 15 July 1995. Note the weak inversion at 700 hPa.

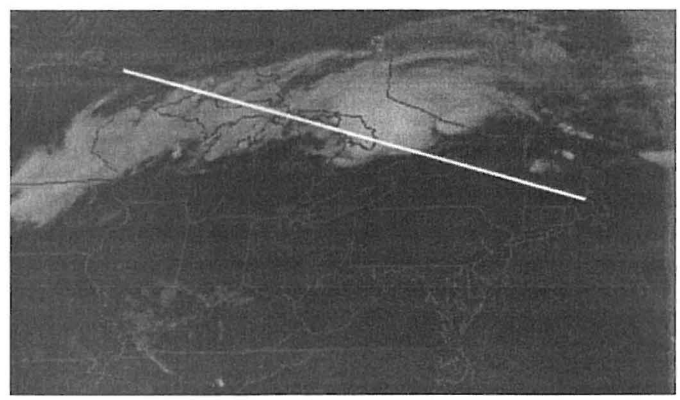

Fig. 14. GOES-8 infrared image, 0615 UTC 15 July 1995. The MCS that produced the derecho is located over southeastern Ontario, just north of Lake Ontario.

UTC 15 July (Fig. 14). Changes in the synoptic-scale environment, as shown by the Eta 18-h forecast, likely contributed to this intensification.

At 850 hPa, moisture transport magnitudes continued to increase from the upper Great Lakes to New York, along the track of the DMCS (Fig. 15). This further destabilized the downstream environment which maximized the gust front's potential to maintain strong convection. The DMCS was located to the east-northeast of the moisture transport magnitude maximum where confluence of the vector field, indicating LLJ convergence, was now occurring.

An increase in cyclonic vorticity advection by the thermal wind over southern Ontario is noted at 700 hPa (Fig. 16). This area of positive thermal vorticity advection suggests that quasi-geostrophic forcing existed in the DMCS environment and produced upward vertical velocities that supported the MCS.

At 250 hPa, divergence from a thermally direct transverse vertical circulation was over the main synoptic-scale forcing region (Fig. 17). The area of maximum divergence was located near where the MCS rapidly intensified. Jet stream induced circulations have been documented as being factors in intensifying DMCS events (Abeling 1990; Schmidt et al. 1990). The cross-section shows significant ageostrophic flow in the region of divergence (Fig. 18). The Eta omega fields also illustrate upward vertical motion at 0600 UTC 15 July (Fig. 19). These intense circulations denoted in the cross-sections are likely the Eta model's representation of convection for this forecast period. Two items supporting this are the nonadiabatic circulation of the ageostrophic wind and the upper-level isentropic deformation denoting latent heating.

c. 1200 UTC 15 July 1995

The DMCS was now beginning to weaken as it interacted with a marine cooled layer near the coastal region of southern New England (Fig. 20). Changes in the synoptic-scale environ-

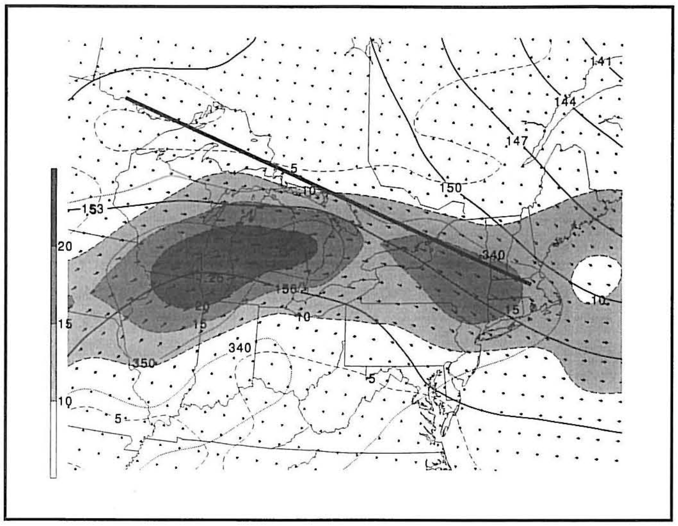

Fig. 15. Eta model 18-h forecast of 850 hPa Moisture Transport (vectors and magnitudes, g kg^{-1} m s^{-1}, dashed lines and shaded), Heights (dm) and Equivalent Potential Temperature (°K, dotted lines) valid for 0600 UTC 15 July 1995. Note: areas of increasing moisture over Michigan and New York.

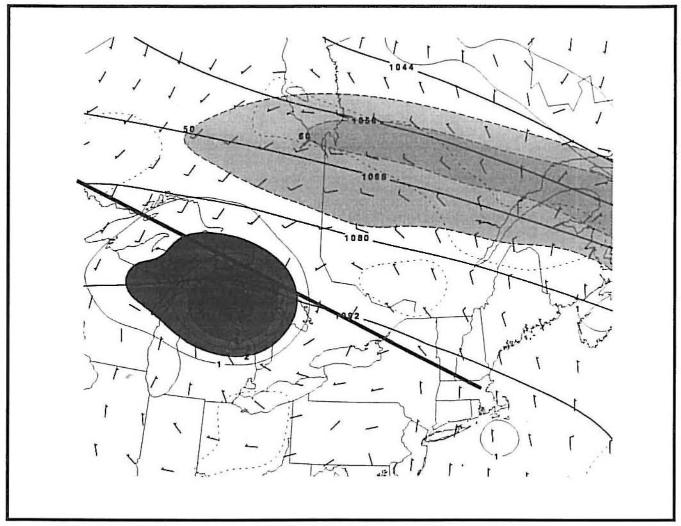

Fig. 17. Eta model 18-h forecast of 250 hPa Divergence (x 10^{-5} s^{-1}, dark shades), Heights (dm), Isotachs (m s^{-1}, light shades) and Ageostrophic Winds (m s^{-1}) valid for 0600 UTC 15 July 1995. Note: the area of divergence over Lake Huron.

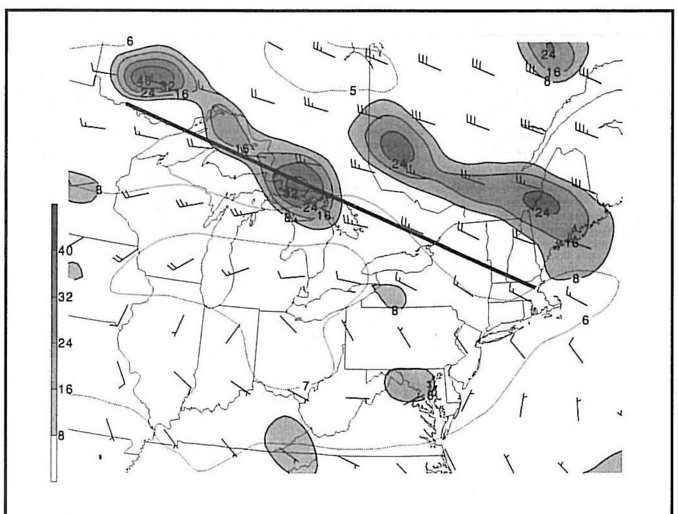

Fig. 16. Eta model 18-h forecast of 500-300 hPa Positive Thermal Vorticity Advection (PTVA, x 10^{-10} s^{-2}, shaded), 850-500 hPa Lapse Rates (°C km^{-1}, dotted lines) and 500 hPa Winds (m s^{-1}) valid for 0600 UTC 15 July 1995.

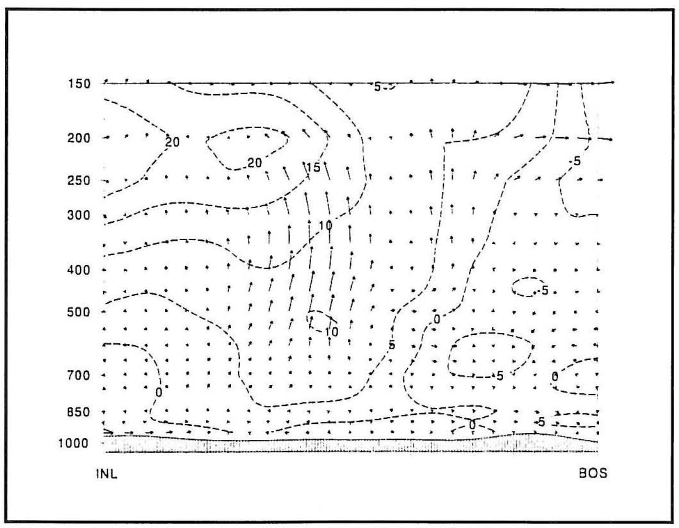

Fig. 18. Eta model 18-h forecast of Ageostrophic Circulation (m s^{-1}) and Isotachs (m s^{-1}) for a vertical cross-section from International Falls, MN (INL) to Boston, MA (BOS) valid for 0600 UTC 15 July 1995. Note: the upward vertical motion between 500 and 200 hPa over southern Ontario.

ment also suggest that a weakening in the DMCS would be expected.

The 850 hPa area of greatest moisture transport magnitude has moved into New York by this time (Fig. 21). This likely assisted the DMCS as it moved across New York by providing an inflow of low-level moisture that maximized the potential energy produced by latent heat exchanges in the system. Upper-air observations also show very strong northwest flow over New York, likely induced by the DMCS (Fig. 21). A height trough through southern Canada is also seen on the 850 hPa analysis. These features are indicative of the ability of the DMCS to alter the synoptic-scale environment it encountered as it progressed through the region. The 700 hPa analysis also shows an area of strong flow in the northeastern United States which was likely enhanced by the elevated rear-inflow jet in the now weakening DMCS (Weisman 1993) (Fig. 22).

At 250 hPa, the 79 m s^{-1} jet streak had weakened to 50 m s^{-1}. An examination of the omega cross-section reveals upward motions still being produced near the leading edge of the DMCS (Fig. 23). This negative/positive omega couplet was likely produced by the updraft and downdraft of the DMCS. The large cold pool of the DMCS appears behind the strong updraft as an area of positive omega values. Another interesting feature of the cross-section is the location of a second area of upward

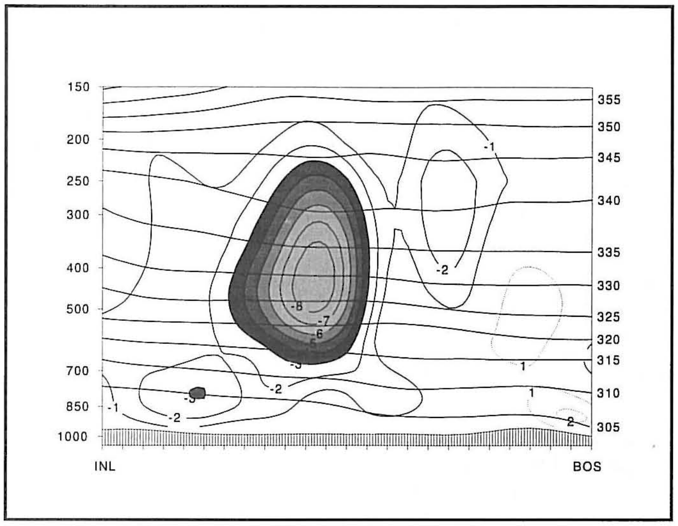

Fig. 19. Eta model 18-h forecast of Omega (x 10^{-3} μb s^{-1}) and Isentropes (°K) for a vertical cross section from International Falls, MN (INL) to Boston (BOS) valid for 0600 UTC 15 July 1995.

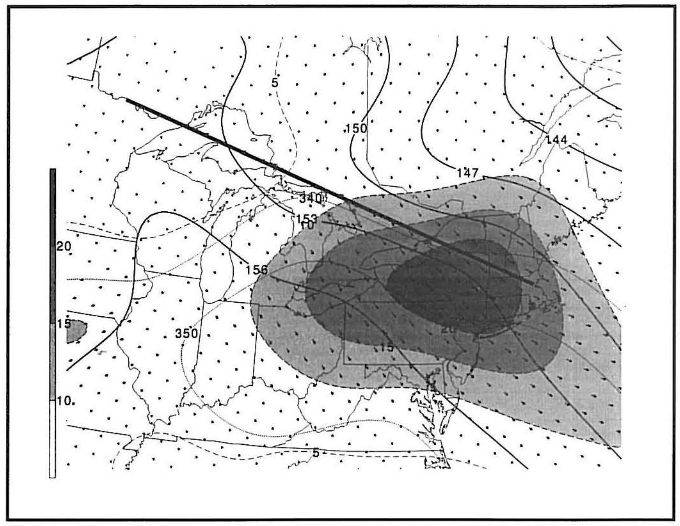

Fig. 21. 850 hPa Moisture Transport (vectors and magnitudes, g kg^{-1} m s^{-1}, dashed lines and shaded), Heights (dm) and Equivalent Potential Temperature (°K, dotted lines) for 1200 UTC 15 July 1995. Note: area of increasing moisture over New York/New England.

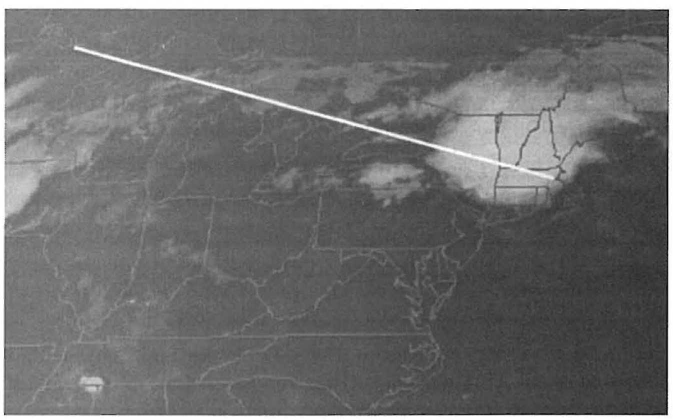

Fig. 20. GOES-8 infrared image, 1215 UTC 15 July 1995. At this time, the DMCS was beginning to move offshore.

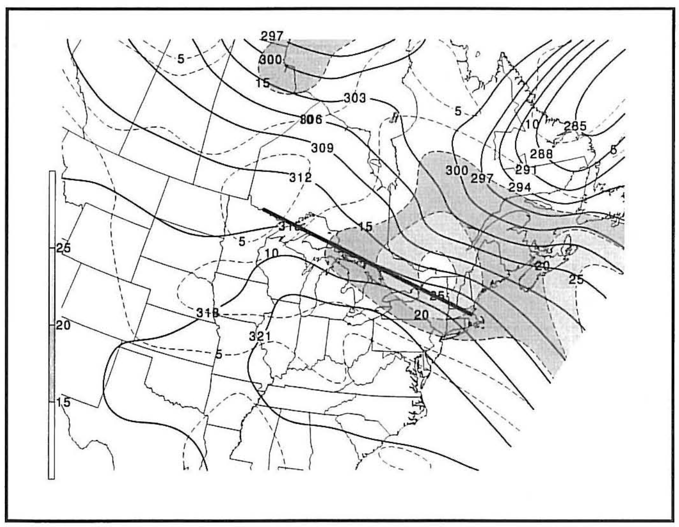

Fig. 22. 700 hPa Isotachs (m s^{-1}, dashed lines and shaded) and Heights (dm) for 1200 UTC 15 July 1995.

motion followed by an area of subsidence. This may be produced by compensating oscillations due to the enormous latent heat exchanges and vertical motions occurring in the DMCS.

4. Discussion

As shown by surface and upper air observations, satellite imagery, and model output, several large-scale features interacted to produce this strong MCS and associated derecho over southern Canada and New England. The major features were:

1) moderate to strong 850 hPa moisture inflow, LLJ convergence and warm air advection over and south of the MCS genesis region
2) abundant low-level moisture leading to increased convective instability
3) the presence of an EML inversion, capping widespread convection
4) moderate to strong northwest flow over southern Canada and the northeastern United States
5) a thermally direct transverse vertical circulation produced by an upper-level jet streak

It appears the primary triggering mechanism was surface convergence from a developing LLJ. This LLJ also provided an influx of moisture into the DMCS genesis region from the highly unstable air under the EML inversion. Also, warm air advection produced lift which assisted in creating a synoptic-scale environment conducive to DMCS formation. Once formed, the MCS moved into a more favorable area for intensification in the prevailing northwest flow on the east side of the ridge. The greatest instability was located east-southeast of the DMCS genesis region. Prior cases indicate that the strongest warm air advection denoting instability, occurs anywhere from south through east of the genesis region in longer track derechos (Johns et al. 1990; Smith 1990).

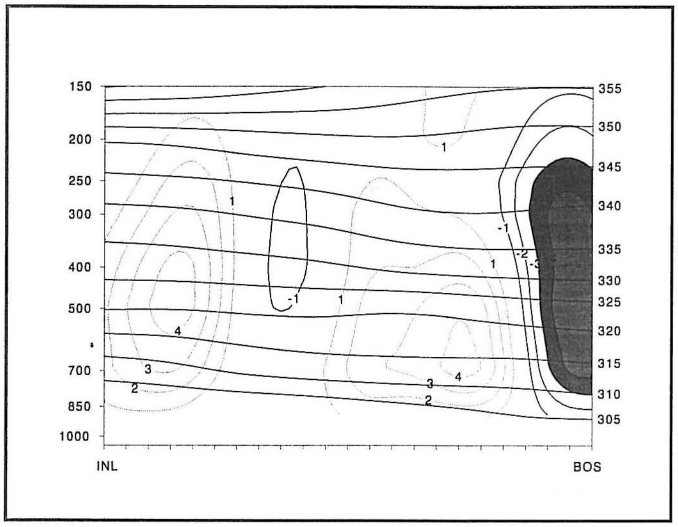

Fig. 23. Vertical cross-section of Omega (x 10^{-3} μb s^{-1}) and Isentropes (K) from International Falls, MN (INL) to Boston, MA (BOS) valid for 1200 UTC 15 July 1995. Note: the omega maximum/minimum couplet near Boston.

Evidence suggests quasi-stationary fronts are a major feature in warm season progressive derecho events (Johns and Hirt 1987). Moisture pooling and low-level convergence along the boundary promotes thunderstorm initiation, while upper-level dynamics play a secondary role in development of the DMCS (Johns and Hirt 1987). In this event, it appears that low-level forcing was the primary synoptic-scale mechanism in initiating the DMCS. Favorable upper-level dynamics resided over the DMCS genesis region; however, this appeared to only support the DMCS. As illustrated, determinations of favorable low-level conditions for DMCS development are assisted by calculating frontogenesis and moisture transport vector fields.

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1996 NWA ANNUAL AWARDS

The 1996 National Weather Association Awards were presented by President Norman W. (Wes) Junker at the 4 December 1996, Annual Awards Banquet. The banquet was held during the NWA Annual Meeting at the Holiday Inn Oceanfront Resort, Cocoa Beach, Florida. Andy Horvitz, the NWA Awards Committee Chairperson, announced each winner and their accomplishments.

Operational Achievement Award - Individual:

Russell L. Pfost, NOAA/NWS Forecast Office, Jackson, Mississippi.

Distinction: As the Science and Operations Officer (SOO) for the NWSFO Jackson, Rusty Pfost put together an exceptional professional development program. He went to great lengths to include collaborative activities with universities, by which the NWS gains from and contributes to their academic programs. His extensive and varied background (forecaster, RFC hydrologist, service hydrologist, MIC and SOO) qualifies him—as relatively few others—as a hydrometeorologist, and he has put that experience to excellent use. As a result of his efforts, staff members are knowledgeable of the most recent meteorological and hydrological analysis and forecasting techniques. Rusty also shares his work with the entire meteorological community. He recently published a paper on bookend vortex tornadoes in *Weather and Forecasting* and another on disastrous Mississippi ice storms in the *National Weather Digest.* He co-authored with Dr. Paul Croft of Jackson State University and two other NWS SOOs, a paper on fog forecasting for *Weather and Forecasting.* In addition, he presented papers on QPF verification and Mississippi coastal flooding at the 1995 NWA Annual Meeting in Houston.

President Wes Junker presenting the Individual Operational Achievement Award to Rusty Pfost. Andy Horvitz announced the citation.

Member Of The Year Award:

William Read, NOAA/NWS Office, Houston, Texas.

Distinction: Bill, personifies the ideals of the NWA's "Member of the Year" Award. He has served in several local and national leadership roles and many more in a support capacity for the betterment of the science, daily operations and the NWA. Bill's outstanding, long-term leadership as an active NWA member, Vice President and Councilor helped in promoting and supporting excellence in operational meteorology and related activities. His superb work as Program Coordinator brought outstanding success to the 1995 NWA Annual Meeting in Houston. In addition, he linked these efforts with his exceptional leadership of the Houston NWS Office as a center of excellence for local research as part of the NWS modernization program. Bill has served either as principal investigator or as resource expert on several projects conducted through the NWS Southern Region CIAMS and Partners Program.

Bill Read accepting the Member of the Year Award from President Wes Junker.