"Route 7 Runner": The May 26, 2010 Severe Weather Event Across the Champlain Valley

Part I: Synoptic and Mesoscale Event Overview, and Radar Analysis

Introduction

On the evening of 26 May 2010 a significant severe weather event occurred across the Champlain Valley of Vermont (VT) and New York (NY). A record breaking air mass was in place across the North Country with temperatures in the upper 80s to mid 90s, which helped to provide a very unstable environment for thunderstorm development. A record high temperature of 92 degrees Fahrenheit (F) was recorded at Burlington, VT, while the temperature reached 96 degrees (F) at Massena (NY), smashing the previous record high temperature of 88 degrees set back in 1978. This record breaking heat combined with a strong backdoor cold front approaching the region from the northeast, to produce a concentrated area of strong to severe thunderstorms across the Champlain Valley during the evening hours on 26 May 2010.

This severe weather event included severe reports of hail up to 1 inch in diameter from Milton to Colchester to Winooski to Castleton, VT, along with numerous reports of trees and power-lines down throughout the Champlain Valley of both VT and NY. Figure 1 shows a map of the severe hail and damaging wind reports across the region.

The damage reports included part of a roof torn-off a house, a boat blown off a trailer, and a measured 59 mph thunderstorm wind gust at Chittenden, VT in Rutland County. Furthermore, the damage path continued across central and southern New England with the complex of storms reaching Long Island, NY during the early morning hours on 27 May 2010.

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Figure 2 below is a Storm Prediction Center (SPC) plot of all severe weather reports, which occurred across the country on 26 May 2010. Notice the extent and concentration of damaging wind reports (blue triangles) from the Champlain Valley to Long Island. Click here for a complete listing of all the severe weather reports across WFO Burlington, VT forecast area.

The scattered thunderstorms resulted in over 15,000 customers losing power across central and northern VT. Click here for a graph showing the time of day and number of people without power across central and northern Vermont. The graph shows the number of people without power on the left axis and the time in which the outages occurred on the bottom axis.

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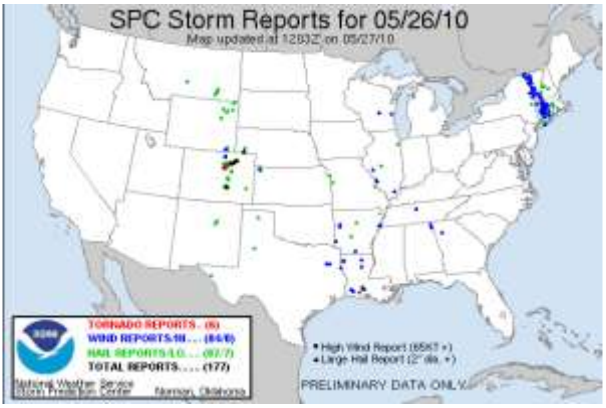

In this post-storm write up, we will investigate the pre-storm synoptic and mesoscale features that contributed to this severe weather outbreak, along with several products issued by the Storm Prediction Center (SPC). This includes examining area soundings for instability and shear parameters, reviewing upper air data for position of short waves and jet streaks, and surface data to identify low level boundaries as a focus for development. Furthermore, an in-depth radar review will be provided with detailed discussions about the reflectivity and velocity signatures that contributed to producing the severe hail and wind reports.

Pre Storm Upper Air Environment:

In this section we will discuss the pre-storm upper air conditions, which helped to produce severe weather across the Weather Forecast Office (WFO) Burlington (BTV) county warning area (CWA).

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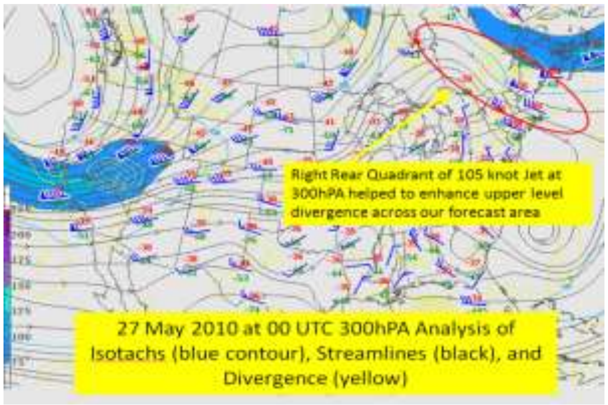

Figure 3 shows the 300 hPa(30,000 feet above the ground level) upper air analysis on 27 May 2010 at 00 Universal Time Coordinate (UTC; i.e. EDT plus 4 hours). Note the 90 to 105 knots across northern Maine associated with departing upper level jet streak.

This right rear quadrant helped to enhance a region of favorable upper level divergence across our region, which is highlighted by the red circle. This area of upper level divergence was associated with upward vertical motion for thunderstorm development.

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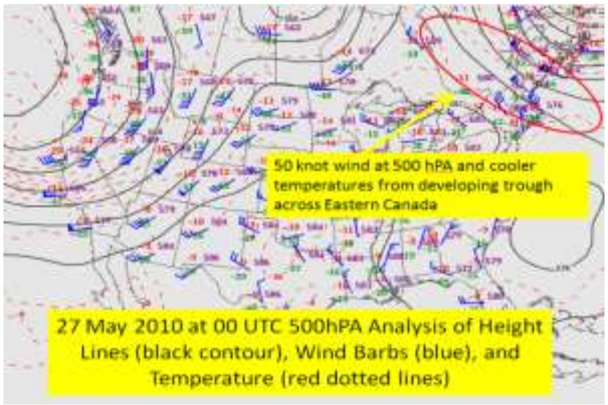

Figure 4 shows the 500 hPa (20,000 feet above ground level) upper air analysis on 27 May 2010 at 00 UTC. This upper air analysis shows a deep closed cyclonic circulation across northern Maine, backing toward Vermont, while a 50 knot wind couplet is streaking across northern New England.

This trough energy and associated cool pool aloft (i.e. temperatures between -16C (Celsius) and -18C) helped to create conditions favorable for storm development, especially given the very warm surface conditions.

Sounding Data:

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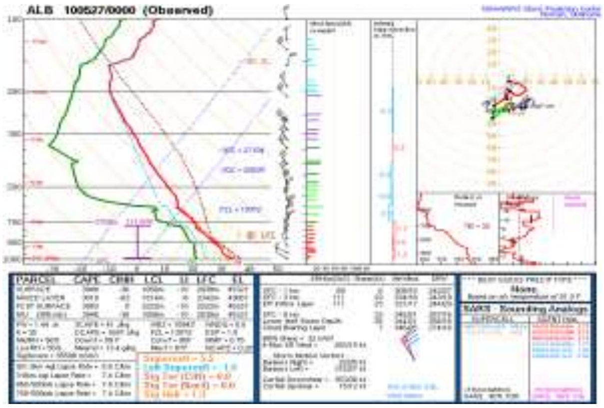

The 00 UTC May 27th rawinsonde observation at Albany, NY (Figure 5) shows extreme instability, but modest deep layer shear, due to the placement of the stronger mid/upper level winds across northern New England. The combination of surface temperatures in the lower 90s and dewpoints in the upper 60s, created surface based convective available potential energy (CAPE) values of 3948 J/kg, with a lifted index (LI) of -10C. CAPE values greater than 1500 J/kg, suggests an unstable environment, favorable for thunderstorm development. The large CAPE profile and very high equilibrium levels indicated the thunderstorms would extend 40,000 to 50,000 feet into the atmosphere, and be capable of producing severe winds or large hail. The equilibrium level is the level at which the rising parcel equals the actual air temperature at that given height, and results in the unstable air now becoming stable and stops rising. In addition, the Albany sounding showed a very deep and well mixed layer from the surface through 600 hPa. This deep mixed layer produced an environment favorable for transporting strong winds to the surface associated with thunderstorm convection.

Surface Analysis and Severe Weather Parameters:

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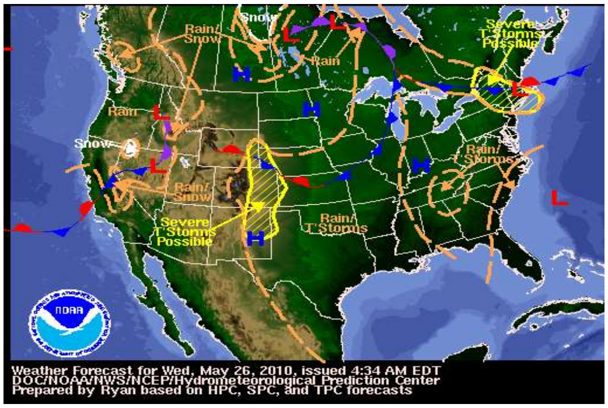

The Hydrometeorological Prediction Center surface analysis showed a strong back door cold front moving across the North Country with a weak wave of low pressure located over southern New England. This low level boundary enhanced convergence, which increased the development of evening thunderstorms across the region.

The northwest to southeast orientation of this boundary separated a cool Atlantic air-mass from a very warm and moist atmosphere across the Champlain Valley and Central/Eastern New York. The focus of this boundary and orientation allowed the storms to organize and develop across the northern Champlain Valley and travel all the way to Long Island NY by early May 27th

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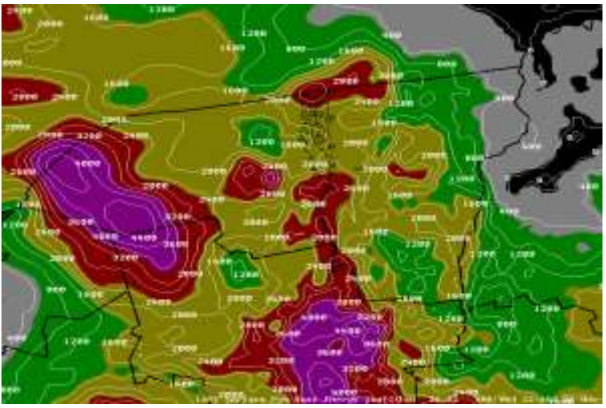

Figure 7 shows the LAPS (Local Analysis Prediction System) CAPE values across the North Country. The red and purple colored filled from the image below indicates CAPE values greater than 2500 J/kg and suggests very high instability parameters. The high potential instability south of the front was contributed to by insolational heating (surface temperatures in the upper 80s to lower 90s), and southerly winds of 10 to 15 mph resulting in surface dewpoint values in the mid to upper 60s.

Note the strong CAPE gradient which ranged from near 500 J/kg over The Northeast Kingdom of VT to 4000 J/kg across the southern Saint Lawrence Valley of NY. In addition, a CAPE maximum was located across the central and southern Champlain Valley, which helped in the development of the strong to severe thunderstorms. Click here for a map of SPC mesoscale surface analysis and click here for the SPC mesoscale discussion.

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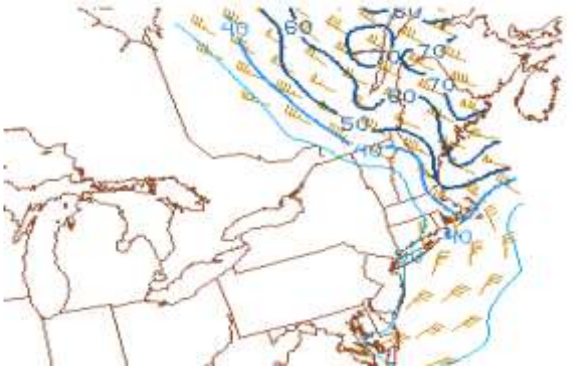

The surface to 6km shear (figure 8) from the RUC (Rapid Update Cycle) at 22 UTC shows an area of increasing shear approaching the region from the northeast. This increase shear was a result of the building mid/upper level trough and several embedded upper level jet streaks. The surface through 6km shear vector denotes the change in wind throughout this height.

Thunderstorms tend to become more organized and persistent as vertical shear increases. Supercells and organized convection, such as squall lines and derechos are commonly associated with vertical shear values of 35-40 knots and greater through this depth. As you can see from figure 8 below the best deep layer (surface to 6km) shear was located across central and northern New England, but was building toward the Champlain Valley as the mid/upper level trough deepen and slowly retrograded back west.

Radar Analysis:

In this section we will discuss in-depth radar signatures and the associated damage with respect to the reflectivity and velocity structures of the cluster of storms.

Click to enlarge

Figure 9 shows a 0.5 degree base reflectivity loop from the KCXX radar in Colchester, VT on 27 May 2010 from 00 UTC to 02 UTC. Scattered thunderstorms developed just north of the International Border around 00 UTC, then moved into the northern and central Champlain Valley by 0030 UTC, and strengthened as the storms encountered increased instability. The brighter/warmer reflectivity colors from figure 9 show locations of very heavy down pours and potential hail. A 60 or greater dBZ return is very high and would suggest the potential for hail and heavy down pours. The storms moved from north to south down the Champlain Valley at 25 to 30 mph. The north to south orientation of the boundary helped to guide the storms down the Champlain Valley, along with the Adirondack Mountains to the west and the Green Mountains to the east.

Click to enlarge

Figure 10 shows a 0.5 degree base velocity loop from the KCXX radar in Colchester, VT on 27 May 2010 from 00 UTC to 02 UTC. The green and blue colors are inbound winds coming toward the radar, while the warmer yellow and red colors are outbound winds going away from the radar. This velocity loop shows several areas of enhanced inbound (blue color) winds, with the first area located across northern Clinton County, just east of Altona, NY at 0010 UTC and another enhanced wind velocity maximum just south of Milton, VT at 0015 UTC. Please note the purple color with very little movement is associated with range folded data, which results in poor radar sampling. After 01 UTC the outbound velocities (warm colors) increase significantly across southern Chittenden County, and then quickly traveled south into western Addison and Rutland Counties. The quick movement of the storms, along with a large area of velocities values between 50 and 65 knots, suggested the potential for damaging thunderstorm winds. The fine line which develops in the 0.5 degree base velocity display at 0130 UTC across northern Rutland County is associated with a cool outflow boundary from the thunderstorm downdraft. This boundary produced straight line winds of 45 to 55 knots, which caused wind damage in Rutland County.

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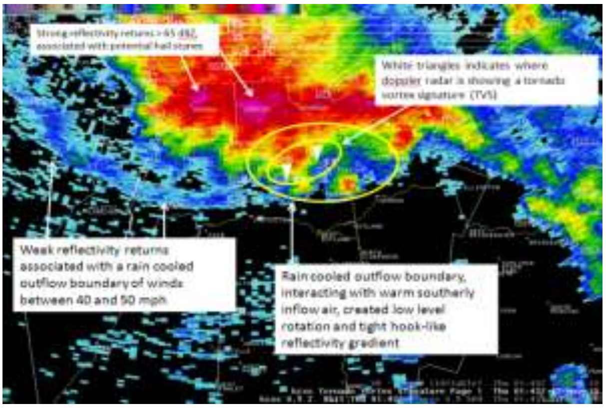

Figure 11 shows a 0.5 degree base reflectivity from the KCXX radar in Colchester, VT at 0143 UTC on 27 May 2010. This low level reflectivity shows a tight reflectivity gradient on the southern flank of the storm, with a weak hook-like structure. Furthermore, you can see a weak outflow boundary interacting with the storm relative inflow on the southern flank of the storm, suggesting the potential for a low level cyclonic circulation. This reflectivity structure suggests the potential for the thunderstorm to produce a tornado, especially if the structure and interaction of low level boundaries persisted. The white triangles show where the KCXX radar is detecting a tornado vortex signature and the potential for a tornado. However, the feature did not persist and no tornado formed from this storm, per results from the NWS storm survey. The pink >65 dBZ returns from the image below show the areas of very heavy down pours, along with the potential for hail. This storm produced 1 inch hail at Florence, VT located in northern Rutland County at 0145 UTC on 27 May 2010, in addition to numerous reports of damaging straight-line thunderstorm winds.

Click to enlarge

Figure 12 shows the storm relative motion (SRM) 0.5 degree scan from the KCXX radar at 0143 UTC on 27 May 2010. The SRM product indicates the velocity within the storm, as if the storm was stationary. The motion of storm is subtracted from the wind field; the result is a picture of the wind as if the storm was stationary. The picture below shows a tight cyclonic gate to gate circulation at 0143 UTC, with inbound winds of 50 knots, co-located next to outbound winds of 45 to 50 knots. The total circulation was near 100 knots, but only persisted for a couple of minutes and was located 4,000 to 5,000 feet above ground level. In addition, strong outflow winds of 50 to 60 knots were present, indicated by the yellow circle in the image below. These winds produced isolated to scattered trees and power-lines down throughout western Addison and Rutland Counties, which was caused by straight-line thunderstorm winds.

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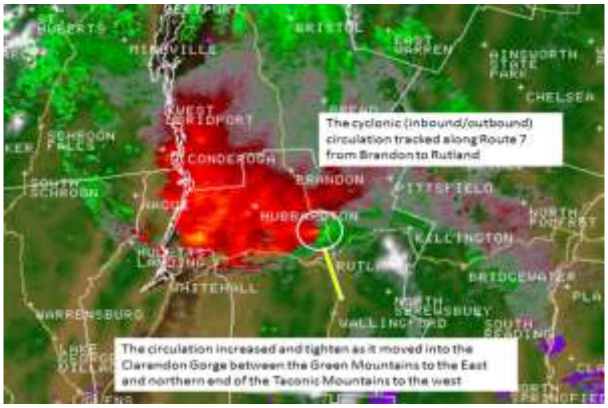

Figure 13 is a close-up image of the storm relative velocity 0.5 degree scan from KCXX radar in Colchester along with a high resolution topography map at 0148 UTC on 27 May 2010. This image shows the low level cyclonic circulation increased in velocity and tightened in diameter as the storm encountered the narrow Clarendon Gorge. The north-south orientation of the valley and steep terrain associated with the Green Mountains to the east and Taconic Mountains to the west, helped to enhance the low level wind field, which resulted in a tightening of the circulation, along with an increase in wind speeds of the inbound/outbound rotational couplet. The radar sampling showed inbound (cool colors) winds of 40 to 50 knots, while outbound (warm colors) winds were also 40 to 50 knots in a very tight couplet with a cyclonic rotation signature, suggesting the potential to produce a tornado. This signature continued for several minutes, before the relatively cool storm outflow raced ahead of the system and cutoff/weakened the circulation. As a result, no tornado formed from this circulation, but numerous areas across Rutland County reported trees and power lines down associated with straight line winds.

Conclusion/Storm Survey and Pictures:

The high instability with modest deep layer shear produced an environment favorable for thunderstorm development during the evening hours on 26 May 2010 across part of WFO BTV forecast area. These storms first developed north of the International Border near Montreal, then tracked south across the Champlain Valley of Vermont and New York, then into southern New England, before slowly weakening across Long Island and the cooler waters of the Atlantic Ocean by early morning on 27 May 2010. The cluster of storms produced 1 inch diameter hail at several locations across the Champlain Valley, along with numerous reports of trees and power-lines down, from straight-line winds. This damage occurred from winds between 50 and 60 mph, with the highest concentration of damage across Addison and Rutland Counties. The pictures below were taken by staff members from the WFO BTV during a storm damage survey.

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Part II: The role of an elevated mixed layer in thunderstorm severity during the evening of 26 May 2010

Part II of this event summary analyzes mid-tropospheric lapse rates and trajectories associated with the severe weather event occurring during the evening hours on 26 May 2010 across the Champlain Valley of Vermont southward across western New England and across Long Island.

Severe weather events in the North Country can occasionally be influenced by an elevated mixed layer - a displaced layer of relatively hot, dry air aloft originating from the Intermountain West or Mexican Plateau (Banacos and Ekster 2010). Such layers play several important roles: (1) they keep a "capping inversion" in place, allowing for a greater buildup of convective available potential energy (CAPE) prior to the initiation of thunderstorms, (2) thunderstorms tend to be taller with more intense updrafts as a result of the greater instability, and (3) convection in EML environs are associated with greater dry air aloft, which contributes to greater downdraft potential and cold pool generation once storms do develop. The EML is also often associated with heat waves, and several daily high temperatures for May 26th were set across New York and New England several hours before the start of the severe weather.

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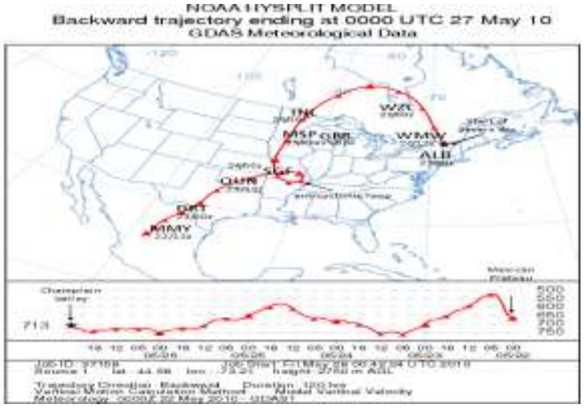

Using NOAA's HYSPLIT model (http://ready.arl.noaa.gov/HYSPLIT.php), we can trace back the air mass within which the first severe storms occurred along the eastern shores of Lake Champlain in the West Milton/Georgia, Vermont area around 00 UTC on 27 May 2010. Figure 1-EML below is a backward trajectory going back 120 hours (5 days).

As can be seen, the trajectory approaches the Champlain Valley in an anticyclonic arc from the North-Northwest, around an anomalously strong upper ridge which was centered across the northern Great Lakes region. The ridge extended north across Ontario, and the trajectory can be seen passing across James Bay around 26/06 UTC.

The trajectory moved along the western periphery of the upper ridge through the upper Mississippi River Valley on the 25th, after completing a complete anticyclonic loop across southern Missouri during the 24th. Prior to that, the air moved across the southern Plains on the 23rd and can be placed back to the high terrain of north-central Mexico on the 22nd. Anticyclonically curved air motion is a common trait of elevated mixed layers which are able to advect large distances; such motion is generally associated with descending air motion which suppresses widespread convective storms and maintains the integrity of the elevated mixed layer over time.

The lower portion of the figure shows a time-height cross section of the backward trajectory. It is notable that the parcel is sinking during its traverse around the upper ridge axis from about 24/18 UTC through 26/00 UTC. There is the start of rising parcel motion shown in the trajectory time-height cross section as the air moves into the Champlain Valley during the evening hours on May 26th. Note also in the top figure that the trajectory reaches or slightly passes an inflection point as it moves into the Champlain Valley; the 700mb flow was becoming slightly cyclonic due to the presence of an upper low over the Canadian Maritimes during the evening of the 26th.

Figure 1-EML also denotes soundings along/near the path of the trajectory, which we will examine next.

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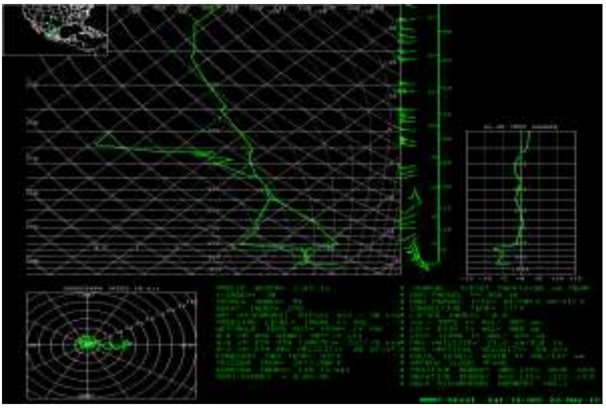

It appears from the soundings that strong insolational heating resulted in a deep mixed-layer over the Mexican Plateau, which is manifest as an elevated mixed layer in the Monterrey, Mexico at 12 UTC on 22 May 2010 (Fig. 2-EML) as the air moves northeastward to lower elevation. The Monterrey sounding shows steep lapse rates in the 800-550mb layer and a strong capping inversion between 850 and 800 mb.

Note also the strong drying apparent at 800mb associated with the interface between the local moist boundary layer and the dry EML which has moved in. Lapse rates are as steep as dry adiabatic (~9.8 C/km) in the 650-550 mb layer.

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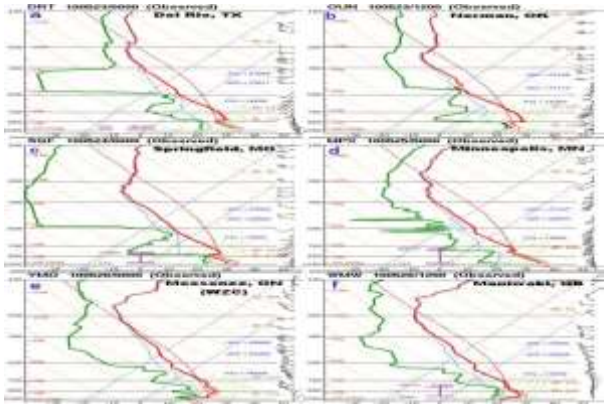

The sounding mosaic in Figure 3-EML shows the general evolution of the EML as it moves northeastward across the central United States and across Ontario.

While the EML changes and becomes somewhat less defined over time, the Maniwaki sounding at 12 UTC on May 26th (Figure 3f-EML) does show a layer of steep lapse rates from 750-550 mb (greater than 8 C/km), and the characteristic increase in relative humidity with height through this layer. The northerly winds allow this plume of steep lapse rates to advect southward into northern New York and Vermont during the day on May 26th.

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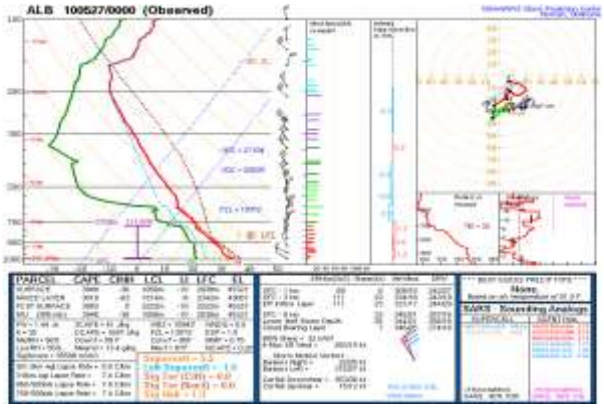

The Albany, NY (ALB) sounding at 00 UTC on 27 May 2010 (Fig. 4-EML) reveals very steep lapse rates from the surface through 600mb, associated with the remnant EML and the hot, well-mixed boundary layer with surface temperatures still in the low 90s during the early evening hours. Resultant surface-based CAPE is nearly 4000 J/kg, which is very unstable for the Northeastern United States. Note also that the equilibrium level on the sounding is near 150mb, and allowed for very "deep" convection to occur.

In addition to the steep lapse rates, the surface to 6 km shear was around 25 kts, which was sufficient to promote thunderstorm organization during the evening hours. The development of the convection occurred on the "cool" edge of the EML plume and the western edge of the stronger deep-layer northerly shear associated with a vertically stacked low over the Canadian Maritimes (this will be more apparent in Fig 5-EML below).

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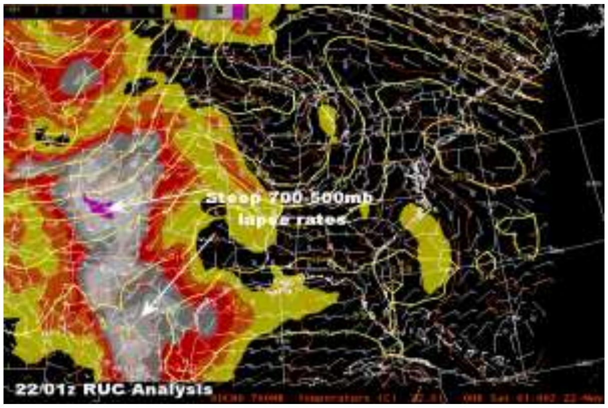

To further detail the movement and evolution of the EML over time, RUC initial hour analyses were used to create a 5-day loop of 700-500mb lapse rates juxtaposed with 700mb geopotential heights, winds, and temperatures. The initial panel is displayed in Fig. 5-EML, and shows the generation of steep lapse rates 8-10 C/km across the higher terrain of the southern Rockies and Mexican Plateau. The 700mb trough moving across the Great Basin aids in ejecting the hot air northeastward as an elevated mixed layer on May 23rd. Meanwhile, a building ridge across the Ohio Valley northward across the Great Lakes into Ontario allows for strong gradient flow to advect the EML plume northward in anticyclonic flow across the lower Missouri Valley into the upper Mississippi river valley on the 24th. While the EML slowly loses definition with time, it is evident that a portion of it remains within the anticyclonic circulation as it moves around the ridge into southern Quebec and New York and Vermont on the 26th. Convective initiation occurs near the eastern edge (cool side) of the EML plume, and along a gradient of increasing 700mb winds associated with the deep low over the Canadian Maritimes on the 26th. Typically, convection will occur on the northern or eastern edge of the EML where convective inhibition not as significant.

The presence of an EML in the northeastern United States is relatively rare. One reason is the distance (>3000 km) from the primary source region of the Intermountain West. Another precluding factor is convective overturning in the form of thunderstorms which typically process and eradicate the EML over the central United States (where the highest concentration of severe weather occurs in the United States). However, in the days leading up to May 26th, we find a lot of anticyclonically curved flow which generally leads to synoptic-scale decent limiting the areal coverage of thunderstorms. Thus, the anticylonically curved flow contributes to maintenance of the EML plume. We can infer the absence of widespread convection near the EML plume by looking at the 24-hour precipitation (12-12 UTC) overlaid with an intermediate snapshot of RUC 700-500mb lapse rates > 7 C/km (which we will loosely define as the edge of the EML plume).

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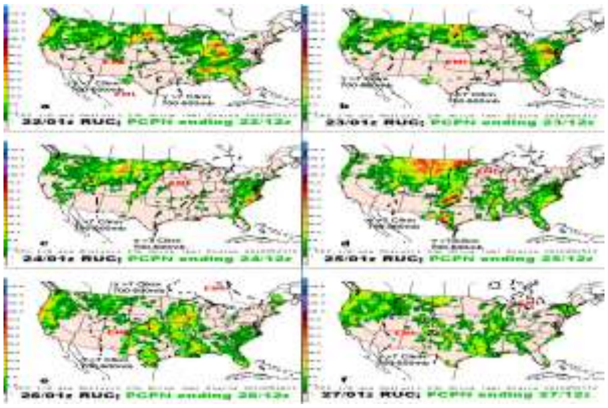

The multi-sensor precipitation analysis for the CONUS is displayed in Fig. 6-EML. Looking specifically at precipitation amounts ending at 12 UTC on May 23rd (Fig. 6b-EML) and May 24th (Fig. 6c-EML), we see a general absence of rainfall across the southern and central Great Plains northeastward into the western Great Lakes region, allowing the EML to move without any significant changes. Precipitation becomes more widespread for the 24 hour period ending at 12 UTC on May 25th (Fig. 6d-EML), especially across Oklahoma, Kansas, and Nebraska. While this decreases the areal extent of the EML plume, there is a smaller, relatively unmodified portion of the EML across the upper Mississippi valley and Great Lakes region that has become entrenched in the 700mb ridge circulation. A portion of this remaining EML plume appears to move across Ontario and into the North Country on the 26th. The precipitation associated with the severe, forward-propagating MCS can be seen on the final panel (Fig. 6f-EML) across eastern New York and New England, and occurs along the eastern periphery of the EML.

In conclusion, the presence of an elevated mixed layer (EML) likely contributed to the overall severity and longevity of the forward-propagating mesoscale convective system (MCS) on the evening of 26 May 2010. The steep mid-tropospheric lapse rates resulted in large CAPE values (up to 4000 J/kg observed per 00 UTC/27th ALB sounding). Likewise, the dry air aloft aided in the development of a strong mesoscale cold pool that aided in the accelerated motion of the MCS. In the days leading up to the event, we showed that southwesterly winds associated with a mid-level trough across the Intermountain West helped eject the EML from the Mexican Plateau, and that the EML plume was able to move northeastward across the southern and central Plains and upper Midwest in the absence of widespread convective overturning, which would have otherwise destroyed the EML. The trajectory analysis suggests anticyclonically curved flow along the EML path which likely suppressed convection until it began to encounter cyclonically curved flow and a highly moist and unstable environment for thunderstorm formation from Montreal, Quebec into the Champlain Valley at 23 UTC on 26 May 2010. Because the air mass is usually capped with EML events, the initiation of convection may be later than normal (around 7 pm in this case) or nocturnal (e.g., past events on 7/15/1995 or 7/5/1999) as a source of lift is necessary to get deep moist convection started. Patience becomes an important attribute for forecasters when severe weather is possible in an EML environment.

Acknowledgements

The NOAA Air Resources Laboratory (ARL) READY website (http://ready.arl.noaa.gov/HYSPLIT.php) was used to generate the HYSPLIT model trajectory shown in Figure 1-EML.

Reference

Banacos, P. C., and M. L. Ekster, 2010: The association of the elevated mixed layer with significant severe weather events in the Northeastern United States. *Wea. Forecasting*, In Press.