The May 9, 2009 Severe Weather Event across the North Country

Introduction

On May 9th, 2009 several meteorological ingredients came together to produce a challenging severe weather event across northern New York and parts of central and southern Vermont. The highest concentration of severe weather occurred from Essex County, New York into Addison, Orange, Rutland, and Windsor Counties across central and southern Vermont. The severe weather reports included a tornado, which was rated an EF1 on the enhanced fujita scale, severe hail, and wind damage. The tornado occurred in Orange County, Vermont near the Village of Washington. The tornado developed around 2100 UTC (5 PM), with the first damage occurring west of Washington, then traveled southeast through the village before dissipating. The length was approximately one half mile, with a width of several hundred yards at its strongest location. The damage included trees uprooted and snapped off, an entire apartment roof was removed, and a steel barn was destroyed. The degree of damage to these structures was consistent with winds ranging from 90 to 100 mph. Click here for the public information statement with regards to the tornado, which occurred in Orange County. In addition to the confirmed tornado, other severe weather reports included, trees down which closed roads near Middlebury, Vermont, one inch hail in Northfield VT, dime size hail near Moriah and Newcomb New York, and several areas of trees down across Windsor and Orange Counties. The scattered thunderstorms resulted in over 5,000 customers losing power across Vermont. This link shows the towns and number of customers without power across central and southern Vermont on the evening of May 9th. In addition, click here for the local storm report, with a complete listing of all the severe weather reports, which occurred across the North Country.

In this post-storm write up, we will investigate the synoptic and mesoscale features that contributed to this severe weather outbreak, along with products issued by the Storm Prediction Center (SPC). Some of the synoptic features which will be discussed include the role of a strong upper level jet and the associated vorticity, along with a west to east orientated surface boundary. Furthermore, an in-depth radar review will be provided, with detailed discussions about the velocity and reflectivity signatures associated with the tornado and severe weather reports. Also, a brief hydro analysis will be given, along with a review of the damage associated with the tornado.

Figure 1 below shows the Storm Prediction Center (SPC) Day 1 outlook for severe weather, along with the highlighted 5% tornado risk across eastern New York and southern Vermont. Click here for SPC's Convective Outlook Day 1 text product, which highlights the severe weather potential and expected convective mode.

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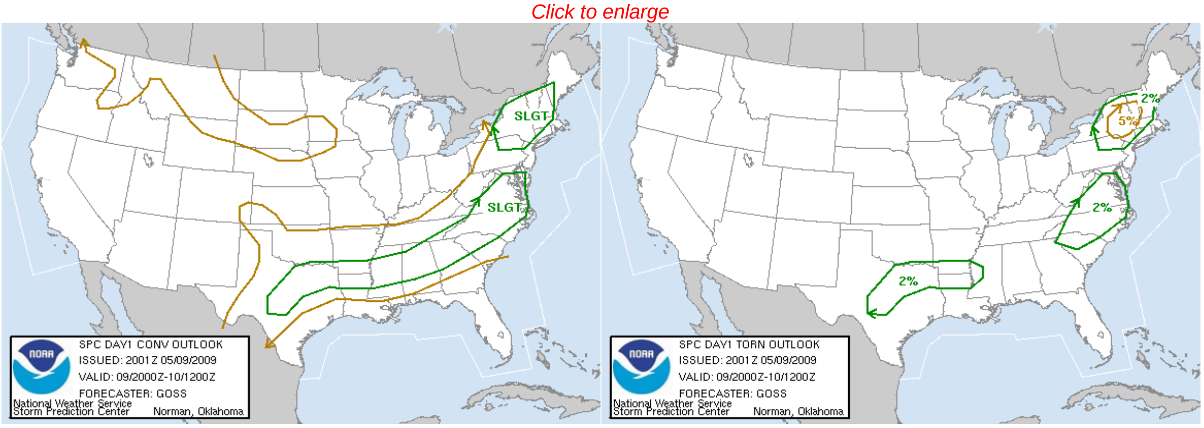

Pre Storm Upper Air Environment

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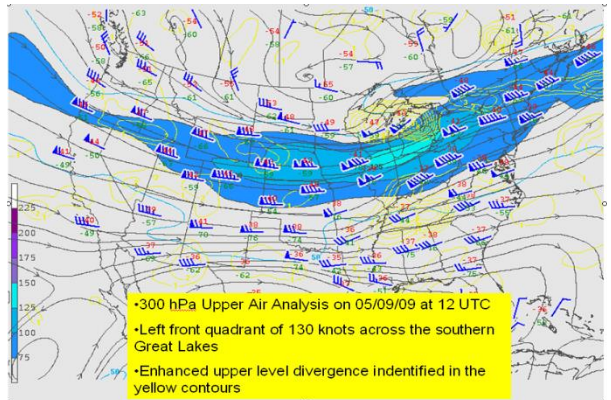

In this section we will discuss the pre storm upper air conditions, which helped to produce severe weather across the WFO Burlington county warning area. This will include 300 hPa (near 30,000 feet above ground level) and 500 hPa (near 20,000 feet above ground level) upper air analysis, along with an investigation of several area soundings.

Figure 2 shows the 300 hPa on May 9th at 12 Universal Time Coordinate (UTC; i.e., EDT plus 4 hours). Note the strong 300 hPa jet stream across the southern Great Lakes into the northeast United States at 12 UTC. Furthermore, note the enhanced upper level divergence in the yellow contours across the central Great Lakes into northern New York. This area of strong upper level divergence associated with a dual jet couplet, helped to promote favorable lift for thunderstorm development across the North Country on May 9th.

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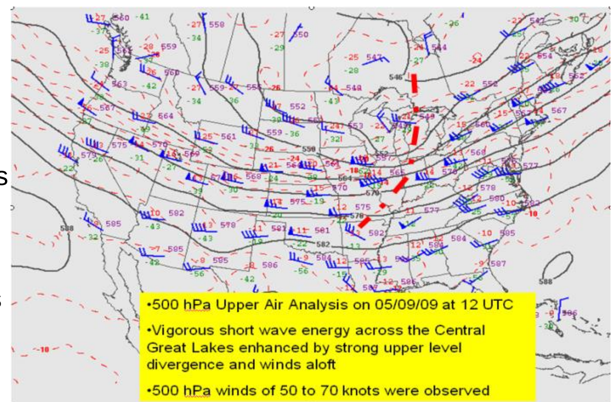
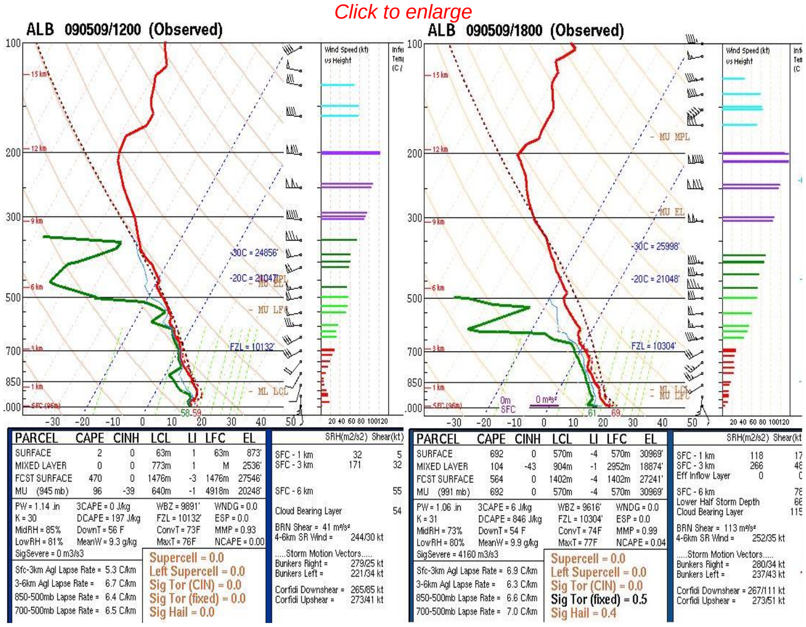


Figure 3 shows the 500 hPa (20,000 feet above ground level) upper air analysis on 9 May 2009 at 12 UTC. This upper air analysis shows a vigorous short wave trough across the central Great Lakes, which was enhanced by strong upper level divergence from the 300 hPa jet couplet. Forcing for ascent associated with the short wave trough allowed convective storms to develop. Furthermore, 500 hPa winds of 50 to 70 knots moving from the central Great Lakes into the northeast United States helped to increase deep layer shear across our forecast area for organized thunderstorm development. The strong winds at 500 hPa and 700 hPa were under forecast by the Numerical Weather Prediction models across our region. The closed low at 700 hPa and 500hPa tracked through southeastern Ontario and southern Quebec, allowing for the band of strong mid-level flow to impact portions of the northern Adirondacks eastward across central and south-central Vermont; the models generally indicated the closed low would instead move across northern New York and Vermont.

Sounding Data

The 12 UTC May 9th rawinsonde observation at Albany showed very limited instability, but strong low to mid level winds helped to enhance the deep layer shear parameters across the region. Some shear parameter from the 12 UTC sounding included: surface to 3km shear of 32 knots, surface to 6 km shear of 55 knots, and the Bulk Richardson Number of 41 m^2/s^2. These values were very impressive and would support organized convection. Meanwhile, some instability parameters included surface based Convective Available Potential Energy (CAPE) values around 10 J/kg and lifted index values near 0C, but lifted condensation levels were around 60 meters, which indicated plenty of low level moisture and low cloud bases. Meanwhile, the non-routine 18 UTC Albany, New York sounding indicated that the low to mid level winds continued to increase, which enhanced the surface to 3 km shear to 48 knots and the surface to 6 km shear to 78 knots, which is extremely strong. The 18 UTC instability parameters increased due to surface heating, with CAPE values around 700 J/kg and lifted index values around -4C, with modest low to mid level lapse rates. Due to some mixing and surface heating the lifted condensation level increased to 570 meters according to the 18 UTC Albany sounding. The figures below show the 12 UTC Albany sounding on the right and the 18 UTC Albany, New York sounding on the right, along with the associated shear and instability parameters.

Click to enlarge



Severe Weather Parameters

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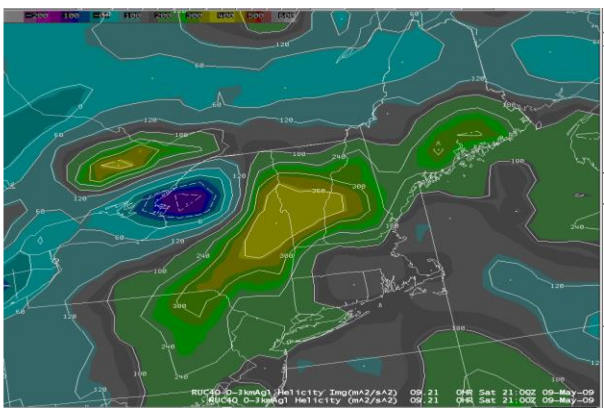

Along and south of the surface frontal boundary in central Vermont, vertical shear and thermodynamic conditions become increasingly favorable for severe thunderstorms during the mid-afternoon hours on Saturday, 9 May 2009. The Rapid Update Cycle (RUC) model indicated westerly surface to 6 km shear values of 60-80 knot across central and southern VT by 20 UTC; this is consistent with the observed 78 knot value on the 18 UTC sounding at Albany. These values of deep-layer vertical wind shear are extreme in the convective environment; typically, surface to 6 km shear of 30-40 knots is sufficient for organized thunderstorm activity including supercell and bow echoes. The storm relative helicity (SRH), which measures the rotational energy along the direction of the low-level wind flow, and the potential for rotating updrafts as inflow air is ingested into the thunderstorm, was also large.

The 21 UTC RUC 0-hr analysis indicated 0-1km (0-3km) SRH of 100 (300) m^2/s^2 near the time and location of the Washington Village tornado (see figure 5 above); these are values typically sufficient for tornado production with supercells. The model derived values are consistent with the 18z Albany sounding which showed 0-1km SRH of 118 m^2/s^2, and 0-3km SRH of 266 m^2/s^2. It is noteworthy that values of deep-layer shear and SRH rose significantly in the Albany soundings between 12 and 18 UTC as wind fields generally increased across eastern New York and central/southern Vermont (e.g., observed 0-1km SRH rose from 32 to 118 m^2/s^2 in 6 hrs).

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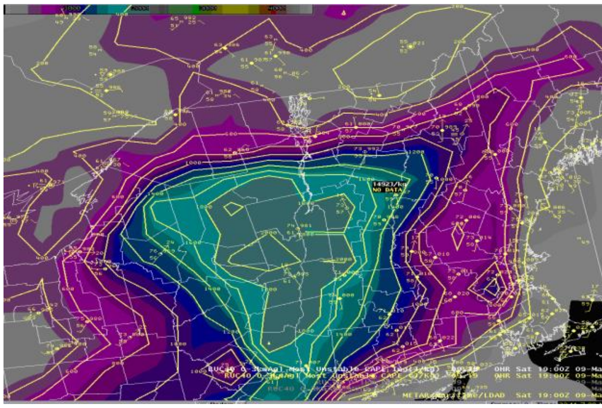

By 19 UTC CAPE had increased to around 1200 J/kg near Montpelier and 1800-2000 J/kg across portions of Essex County NY and Rutland County VT per RUC 0-hr analysis. See figure 6 for RUC CAPE analysis. There existed a sharp instability gradient collocated with the surface front across north-central Vermont.

The moderate potential instability south of the front was contributed to by insolational heating (surface temperatures in the low to mid 70s), and southerly winds of 10-15 knots resulting in 55-59F surface dewpoints streaming northward across the upper Hudson Valley of New York and southern and central sections of Vermont. Given the strong deep-layer shear in place, these values of CAPE were sufficient to support severe thunderstorms. The observed 18 UTC CAPE at Albany was 692 J/kg. Another favorable factor contributing toward destabilization south of the front were steepening mid-level lapse rates, with 700-500mb values at Albany increasing from 6.5 C/km at 12 UTC, to 7.0 C/km at 18 UTC.

Surface Analysis

Figure 7 below is a 19 UTC satellite with lightning and surface observations. Note the strong front with north winds being observed at Burlington, VT with a temperature of 61F. Meanwhile at Montpelier, VT south winds were observed with a temperature in the mid 70s and surface dewpoint in the mid 50s. This boundary was enhanced by significant clearing across central/southern Vermont, which helped to warm temperatures into the 70s, while clouds and moderate rain north of the surface boundary held temperatures in the upper 50s to lower 60s. This strong frontogenetical forcing helped to enhance low level shear and convergence across central Vermont, which promoted organized convection and an environment favorable for tornado producing thunderstorms. Figure 6 above shows the most unstable CAPE values south of this boundary across central and southern Vermont were between 1500 and 1800 J/Kg. This boundary was significantly under forecasted by the numerical models, because the models underestimated the amount of differential heating. Furthermore, weak surface low pressure moving along this low-level thermal boundary, helped to further enhance the 0-1km shear values across central Vermont. It should be noted very heavy rainfall of 1 to 3 inches was observed along and north of the surface boundary from Essex County, New York through Lamoille County, Vermont.

In addition, to a west to east surface boundary, this system had very strong upper level dynamics, which promoted deep-layer lift across our forecast area. Click here for SPC's mesoscale discussion, with regards to pre-storm severe weather parameters and the issuance of a watch box. Click following the MCD numbers to display the graphics #778 and #781.

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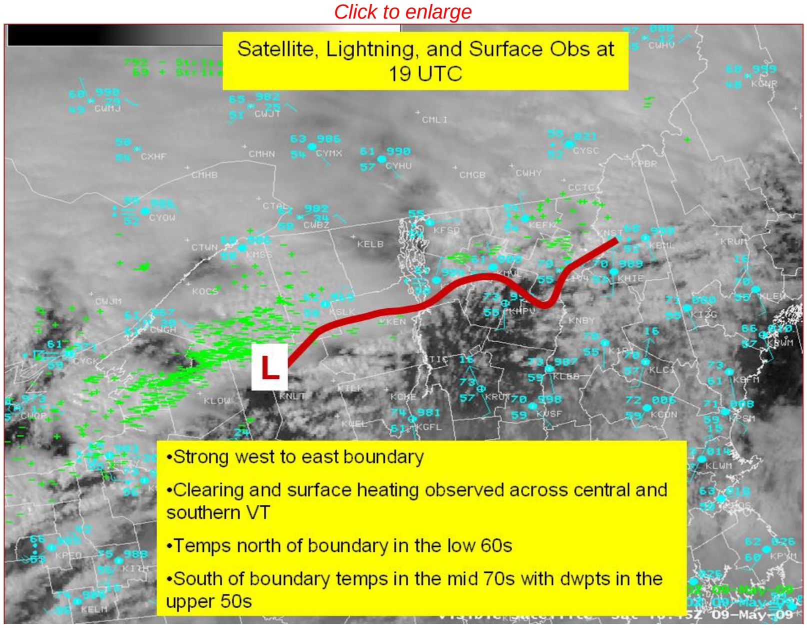
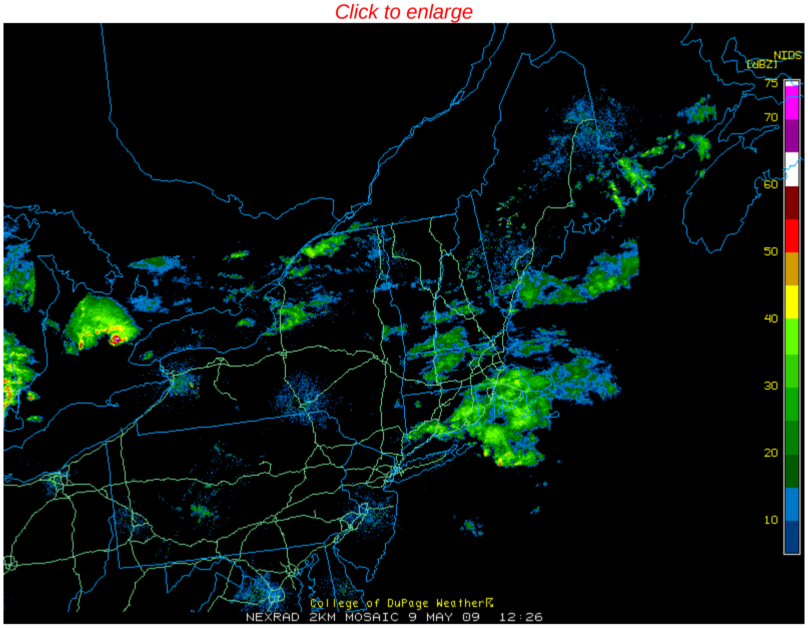


Radar Analysis

In this section we will discuss in-depth radar signatures and the associated damage associated with the reflectivity and velocity structures. The first image below is a 24-hour radar mosaic from the College of DuPage centered across the eastern Great Lakes and the Northeast region of the United States. Note from the reflectivity structure below that the convective complex tracked from the eastern Great Lakes into northern New York, then into central Vermont by early evening on May 9th. The reflectivity structure supported a strong cyclonic rotation, which was a result of the potent dynamics/jet stream winds aloft, which enhanced this mesoscale convective vortex (MCV). An MCV is a low-pressure center within a mesoscale convective system (MCS) that pulls winds into a circling pattern, or vortex. With a core only 30 to 60 miles wide and 1 to 3 miles deep, an MCV is often overlooked in standard weather analysis and can persist for up to 12 hours. This structure produced several embedded bow echo line segments across our forecast area, with significant wind damage occurring on the apex of the bow and in the comma head portions of the convectively induced vortex. In addition, note the fast movement of the convective complex, which suggests the potential for strong and damage thunderstorm winds.

Click to enlarge



Middlebury Vermont Radar Analysis

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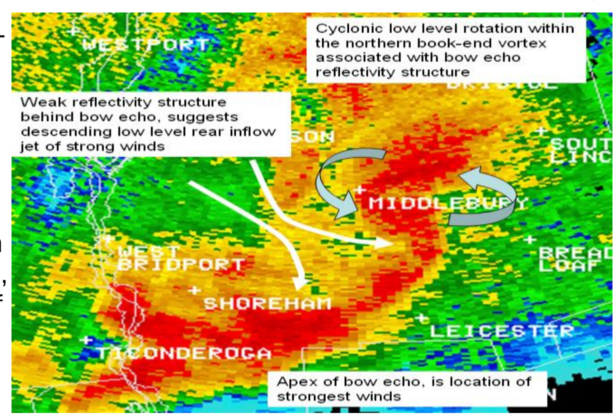
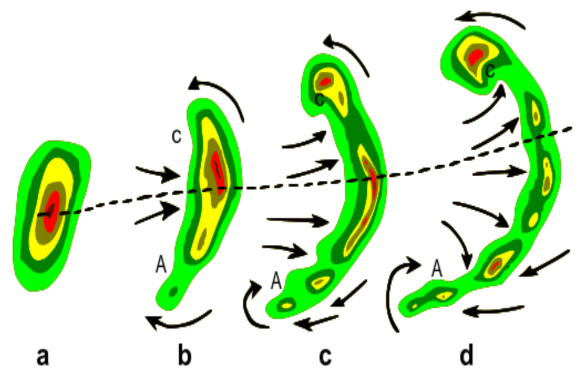


Figure 9 is the 0.9° reflectivity slice from the KCXX radar at 2041 UTC on May 9th. The reflectivity structure showed a bow echo with a prominent rotating comma head structure, which formed by 2041 UTC. Two regions of significant wind damage occurred within this MCV. The first area of damage was observed near Middlebury, Vermont which appeared to be produced in association with the northern bookend vortex developed by this bow echo. Bookend vortices are small scale rotating cells, which are observed at the ends of a line segment of convective storms, usually cyclonic circulations are observed on the northern end of the system. Figure 11 shows the 0.9° velocity at 2041 UTC on May 9th, which is the radar measurement of winds coming toward and away from the radar. The tight couplet of red and green colors near Middlebury, Vermont, indicates cyclonic rotation associated within the northern bookend vortex. The second area of damage was associated within the apex of the bow echo reflectivity structure, just a couple miles south of Middlebury, Vermont. The limited reflectivity observed on the backside of this bow like apex, suggests strong descending winds associated with rear inflow jet.

Click to enlarge

Figure 10 shows the typical evolution of a thunderstorm radar echo (a) into a bow echo (b, c) and into a comma echo (d). Dashed line indicates axis of greatest potential for downbursts. Arrows indicate wind flow relative to the storm. Note regions of cyclonic rotation (C) and anticyclonic rotation (A); both regions, especially C, are capable of supporting tornado development in some cases.



This reflectivity structure is very similar to the 0.9° reflectivity data observed in Addison County on May 9th (See figure 9 above)

Click to enlarge

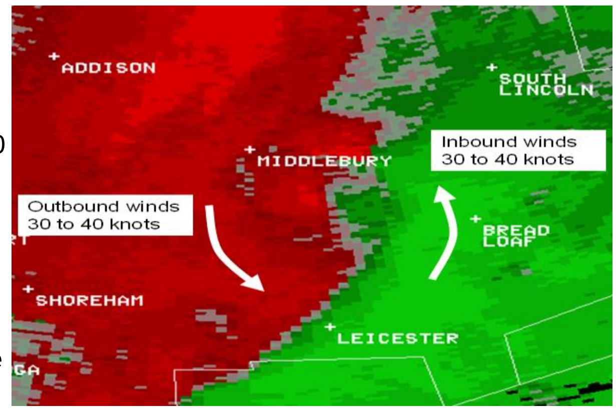


Figure 11 shows the KCXX 0.9° velocity at 2041 UTC across Addison County, Vermont. The red colors indicate winds moving away from the radar, while green colors suggest winds moving toward the radar located in Colchester, Vermont. The velocity sampling shows outflow winds moving away from the radar at 30 to 40 knots just south of Middlebury associated with the apex of the bow echo. Meanwhile, inbound (green color) winds just east of Middlebury measured 30 to 40 knots. The tight inbound/outbound couplet just east of Middlebury, suggests some weak cyclonic rotations, within the bookend vortex. Also, given the storm was moving perpendicular (west to east) to the radial beam, suggests the velocity data was underestimated due to poor radar sampling. The yellow circles in figure 11 indicate two potential areas of cyclonic rotation, with the bow echo line segment. This area would be the most favorable region for tornado development with the MCS.

<u>Orange County, Vermont Radar Analysis of Tornadic Thunderstorm</u>

In this section we will discuss the radar signatures associated with the tornadic thunderstorm, which occurred over central/western Orange County, Vermont near the town of Washington. This isolated storm along a strong surface boundary, exhibited mini supercell characteristics. Supercell thunderstorms are the largest and are generally the most severe type of thunderstorm, often capable of producing tornadoes, large hail, severe winds, heavy rainfall, and frequent lightning. In addition, supercells are often isolated from other thunderstorms, and can dominate the local climate up to 20 miles away.

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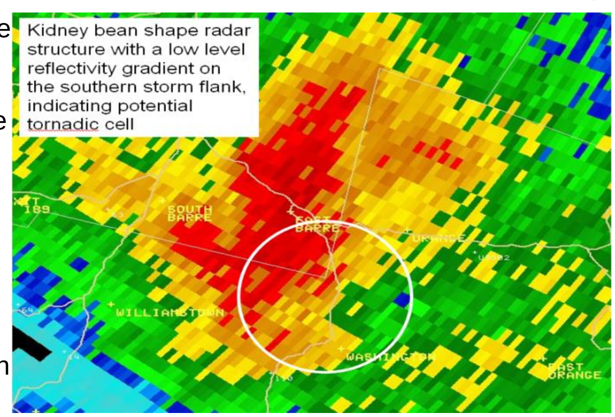

Figure 12 shows the 0.9° reflectivity structure associated with the tornadic mini supercell across central Orange County, Vermont near the town of Washington on May 9th. The kidney bean structure of the low-level reflectivity indicates the potential for the storm to produce a tornado. In addition, the sharp hook like reflectivity gradient on the southern flank of the storm, suggests the potential for the storm to produce a tornado. It should be noted, due to complex terrain from the Green Mountains in Central Vermont and the distance away from our radar in Colchester, Vermont, our radar had very poor sampling of this particular storm in the low elevation angles. This makes the warning decision making process extremely difficult, especially in these situations.

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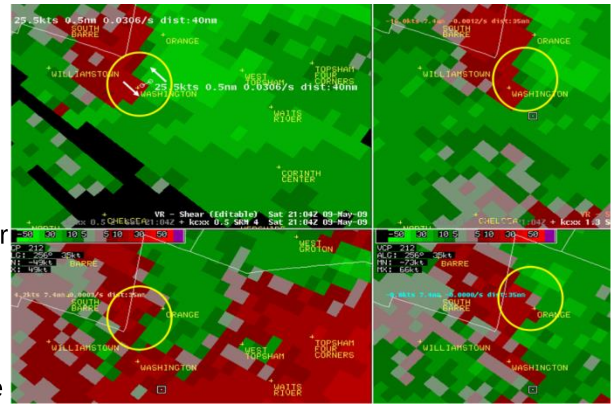

Figure 13 shows the lowest four degree elevation scans (0.5°, 1.3°, 2.4°, 3.1°) of the storm relative velocity at 2104 UTC from the KCXX radar in Colchester, Vermont. The storm relative velocity product is used by warning meteorologists to determine the amount of rotation, within a particular storm. The green colors from figure 13 shows winds coming toward the radar, while the red color are winds moving away from the radar. The closer and brighter the inbound and outbound winds are together the tighter and usually the stronger the storm rotation is, and the better chance the storm can produce a tornado. The inbound winds (green color) were 30 to 40 knots, while the outbound winds (red color) were 20 to 30 knots near the town of Washington, Vermont. The Vr-shear tool indicated low level gate to gate weak cyclonic rotation of 25.5 knots in a 0.5 nautical mile diameter. The rotation was observed thru a deep layer (7000 feet) in the atmosphere and persisted for several radar volume scans. Furthermore, strong westerly winds 50 to 70 knots aloft, produced a tilted updraft, which enhanced stretching of the horizontal vorticity (spin). These factors contributed to tornado development.

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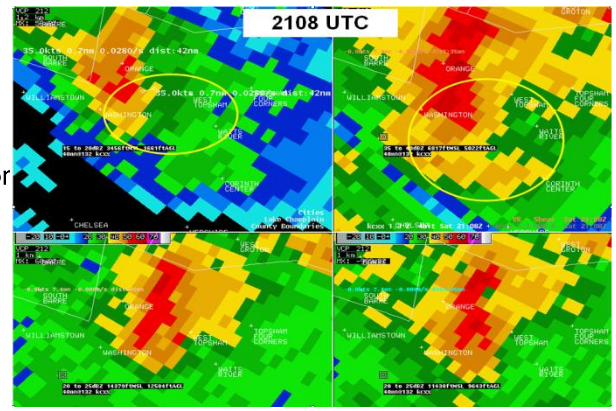

Figure 14 shows the lowest four degree elevation scans (0.5°, 1.3°, 2.4°, 3.1°) of reflectivity at 2108 UTC from the KCXX radar in Colchester, Vermont. The 0.5? slice shows limited reflectivity due to beam blockage from the Green Mountains in central Vermont. However, the 1.3° slice (upper right) shows a well defined hook-like echo structure, which suggests the potential for a tornado. In addition, the white numbers in the upper left hand image shows the Vr-shear tool measurement of low level gate-to-gate rotation of 35 knots. This increased from 25 knots at 2104 UTC to 35 knots at 2108 UTC, indicated a strengthening low level cyclonic circulation, near the town of Washington in central Orange County, Vermont. Furthermore, the two upper level reflectivity images show a tight reflectivity gradient on the southern flank of the storm, which was located just east of the town of Washington at 2108 UTC. The increased cores of the brighter oranges and reds in the reflectivity structure in the higher levels, suggested a bounded weak echo region (BWER), which indicates the storm had a strong updraft to hold the heavy precipitation aloft. The BWER is a radar signature within a thunderstorm characterized by a local minimum in radar reflectivity at low levels which extends upward into, and is surrounded by, higher reflectivities aloft. This feature is associated with a strong updraft and is almost always found in the inflow region of a thunderstorm and, if strong enough, can lead to the production of severe hail.

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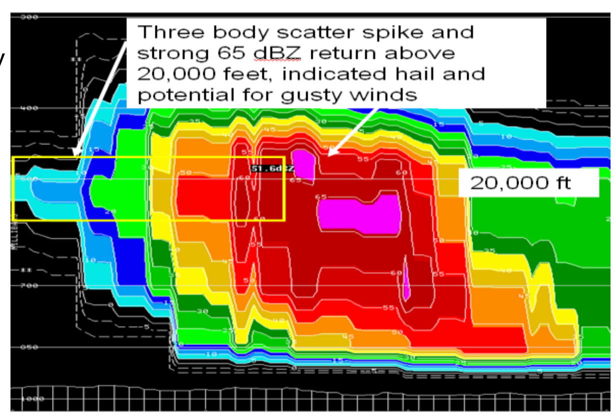

Figure 15 is a composite reflectivity cross section taken across northern Windsor County, Vermont at 2115 UTC. This reflectivity structure was associated with an MCV, which crossed across Addison and Rutland counties on May 9th, then redeveloped over northern and central Windsor County. This particular storm downed trees near Bethel, Vermont. It also produced dime size hail and wind damage at Silver Lake State Park at 2120 UTC on May 9th. There is also a three body scatter spike (TBSS) evident, which is a radar artifact indicative of large hail. In addition, the strong 65 dBZ to 20,000 feet suggests the storm had a very strong updraft and when it collapsed strong winds and hail were transferred to the surface. In figure 15, limited reflectivity was observed in the lowest couple thousand feet due to the elevation of the beam intersecting the storm, and poor sampling due to the beam blockage from the Green Mountains. This makes the severe weather warning decision-making process across the North Country extremely difficult, especially during complex and changing convective storms that occur in the warm season.

Hydro Concerns

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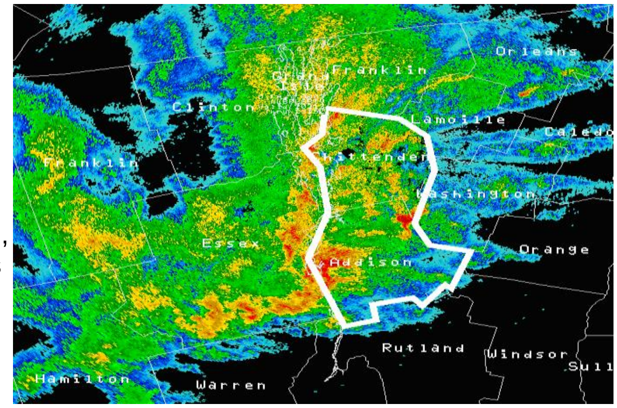

As scattered showers with embedded thunderstorms continued to move across the County Warning Area, urban and small stream flooding also became a concern. An urban and small stream flood advisory was issued at 2021 UTC in advance of a band of thunderstorms with heavy rain moving into Chittenden and Addison Counties in western Vermont.

This area had some rain ahead of this line of heavy precipitation, and minor issues were reported from drainage backup problems across the region.

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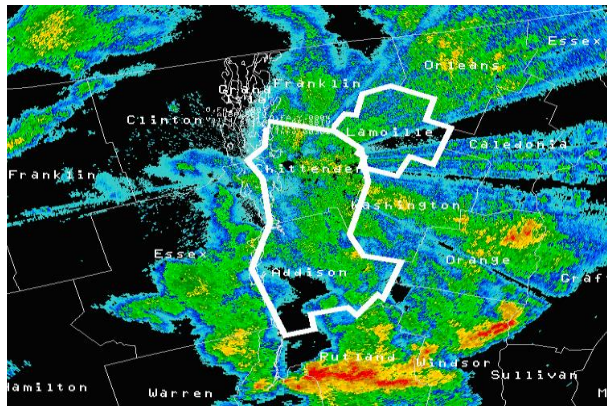

A small stream flood advisory was issued at 2132 UTC for Lamoille County as heavy rain from thunderstorms and moderate rain showers caused rapid rises on area streams and creeks, as well as some poor drainage flooding.

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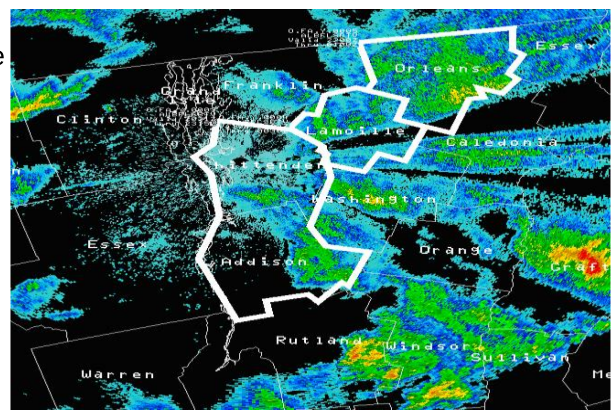

A small stream flood advisory was issued at 2200 UTC for Orleans County as heavy rain from thunderstorms and moderate rain showers caused rapid rises on area streams and creeks, as well as some minor backups in poor drainage areas.

After rain moved out of the area, each of the flood advisories was cancelled as the threat for minor flooding subsided.

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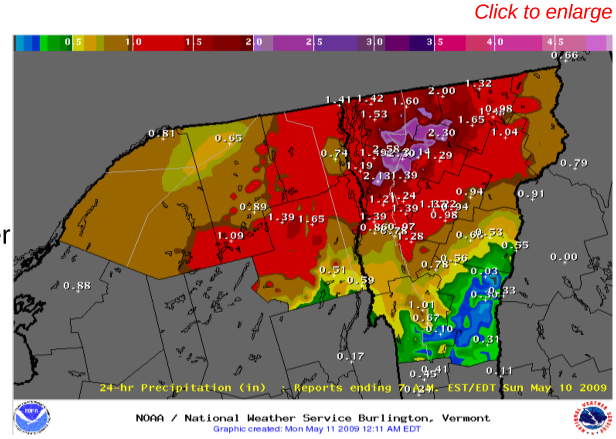

Twenty-four hour rainfall totals on Sunday morning were over two inches in parts of Orleans, Lamoille, and Chittenden Counties. The highest rainfall total of 3.18" was recorded at the Jeffersonville, Vermont Co-Op station.

Addison County had slightly lower totals with three-quarters of an inch to an inch and a half of rain, although experienced higher rainfall rates as significant bow echo traversed the county.

Damage Survey/Summary

A damage survey was conducted on Sunday May 10, 2009 in the Village of Washington, Orange County, VT. The tornado was rated an EF1 on the enhanced Fujita scale. It moved through the area around 21 UTC. The tornado first caused damage west of Washington, then traveled east-southeast through the village before dissipating. The length of the path was approximately one half mile. Multiple eyewitnesses observed the tornado as it crossed the village. The debris pattern also supported the rotating winds experienced in a tornado. Some debris was blown downwind along the tornado path, while other debris was blown at right angles to the path.

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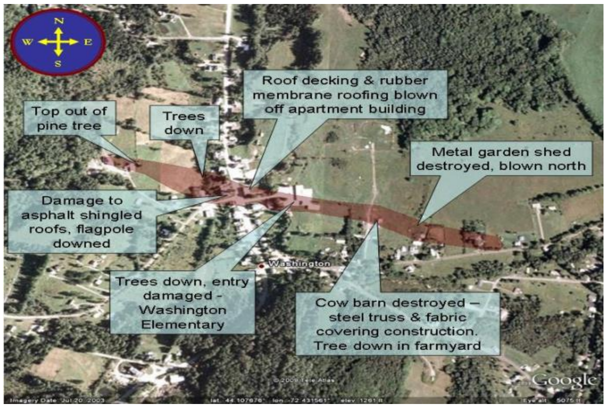

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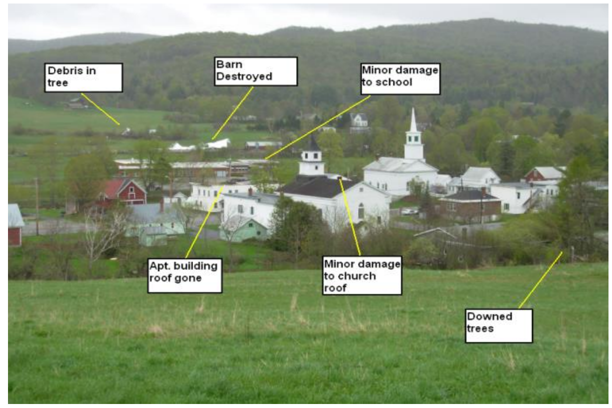

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The damage was sporadic and variable across the path. Some trees were snapped while others were uprooted. An entire roof was blown off an apartment building. Also, a steel and membrane barn was destroyed. The degree of damage to these structures is consistent with winds ranging from 90 to 100 miles an hour. The EF1 intensity winds range from 86 to 110 mph. Table 1, found below, shows the Enhanced Fujita Scale.

Tornadoes are relatively rare in Vermont. On average, one tornado is reported every two years. A tornado occurrence in May is even rarer. This tornado was the second earliest confirmed tornado in the state since 1950.

The earliest tornado on record occurred in Bennington County on March 22, 1955. That tornado was rated an F2 on the old Fujita scale.

Enhanced Fujita Scale Number	3 Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	200+

Table 1: Enhanced Fujita Scale