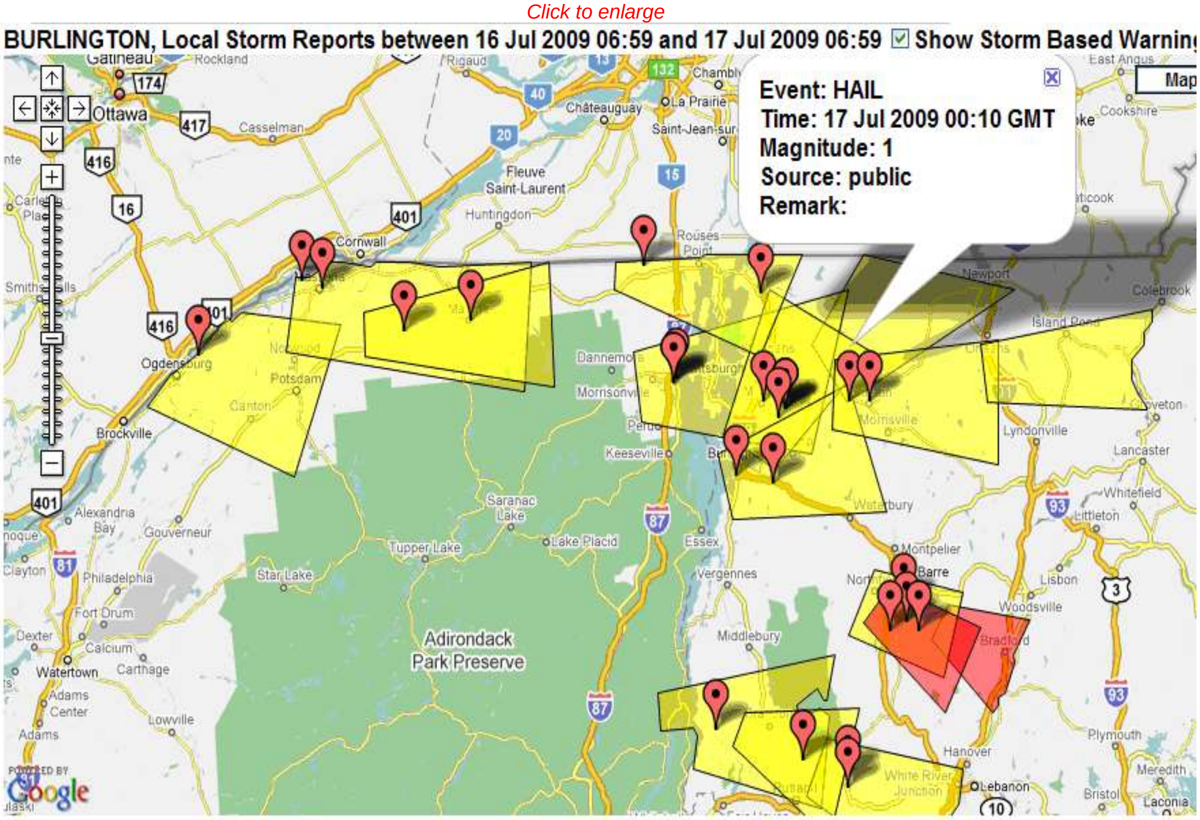
The 16 July 2009 Record Breaking Hail and EF0 Tornadic Event across Vermont

On 16 July 2009 a significant severe weather event occurred across northern New York as well as central and northern Vermont. This event included several long lived supercell thunderstorms, which produced an EF0 tornado near Williamstown, Vermont and over 3 inch diameter hail in Westford, Vermont. A National Weather Service (NWS) storm survey team estimated maximum winds ranged from 55 to 75 mph associated with this weak EF0 tornado. Click here for the Public Information Statement (PNS) completed by the damage survey assessment team. The supercell near Westford produced the largest hail stone ever documented in Vermont. This record breaking hail stone measured 3.3 inches in diameter, had a circumference of 6.8 inches, and weighed 2.1 ounces. In addition, several areas reported trees and power-lines down, caused by severe thunderstorm winds. In this write up, we will investigate the pre-storm environmental conditions which were present and favorable for producing supercell thunderstorms. Furthermore, we will examine radar data from the left splitting storm, which produced over 3 inch hail near Westford and the tornadic producing thunderstorm near Williamstown. For a complete list of all the severe weather events reported to the NWS in Burlington, click here. Figure 1 below shows a map of the local storm reports across the NWS Burlington, Vermont County Warning Area (CWA), along with the severe thunderstorm polygons in yellow and the tornado polygons in red.

Click to enlarge



Pre-Storm Environment: Storm Prediction Center Outlooks

In the pre-storm environment section we will review the Storm Prediction Center's (SPC) severe weather outlooks, along with thermo-dynamic soundings and upper air data across the region, to gage the amount of shear and instability in the atmosphere. Furthermore, we will investigate LAPS (Local Analysis and Prediction System) and RUC (Rapid Update Cycle) data to uncover boundaries and low level gradients across our forecast area and examine the amount of shear and instability over the region.

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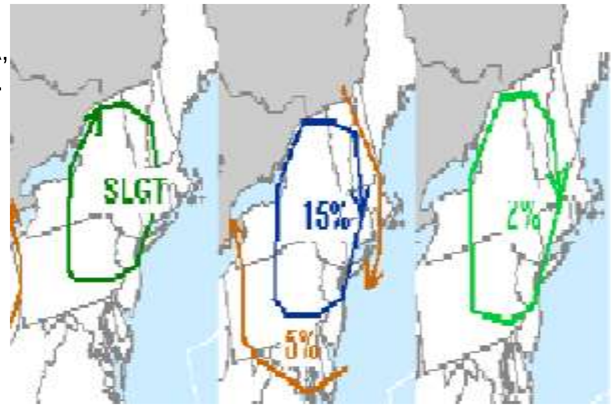

Figure 2 shows the SPC'S day 1 convective outlook, along with the probabilistic outlooks for hail and tornadoes across our CWA, produced at 13 UTC (Universal Time Constant) on 16 July 2009. This shows that Weather Forecast Office (WFO) Burlington's CWA was in slight risk for severe thunderstorms on July 16th, along with a probabilistic 15% chance for severe hail, and 2% chance of a tornado.

It is very uncommon for Vermont to be in the forecast risk of tornadoes. Click here to read the detailed severe weather outlook day 1 forecast from SPC. Both the hail and tornado forecast was excellent, given we had record breaking hail size and a confirmed tornado in our CWA.

Pre-Storm Environment: Upper Air

The next section to examine in the pre-storm environment is the 12 UTC sounding and upper air data across the region. This data was very interesting with the regards to the deep dry layer, which was observed in local soundings and the increased upper level jet approaching the region from southern Canada. This jet energy combined with the deep dry layer produced conditions favorable for isolated to scattered supercells across our CWA. However, when the dry layer is exceptionally dry and deep it may prevent storms from developing, with only towering cumulus clouds observed. Therefore it is very difficult to forecast the impacts of dry air aloft and it's potential effect on the areal coverage/intensity of storms, especially in an unstable environment as the case on 16 July.

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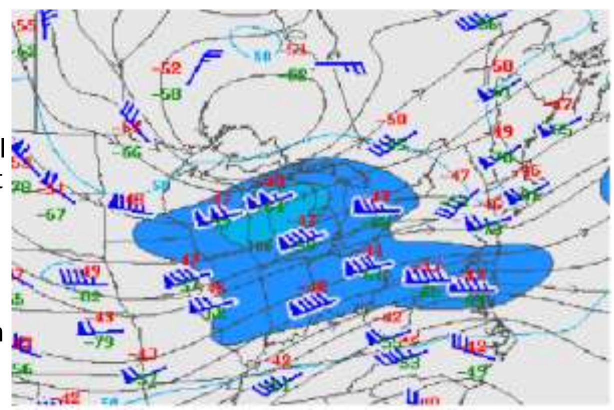

Figure 3 shows the 17 July 2009 upper air analysis at 00 UTC near jet stream level at 250 hPa (near 35,000 feet above the ground). Note the strong 90 to 110 knot upper jet (region outlined in blue) approaching western New York at 00 UTC on July 17th. In addition, this strong jet energy extended into central and southern New England with Gray, Maine reporting a 65 knot winds at 250 hPa at 00 UTC.

These strong jet winds helped to enhance storm top divergence and increase the deep layer shear across the region, which supported thunderstorm organization and growth. The jet stream orientation and position placed our forecast area in the left front quadrant of enhanced winds, which is the region that characteristically experiences the best lift and storm top ventilation.

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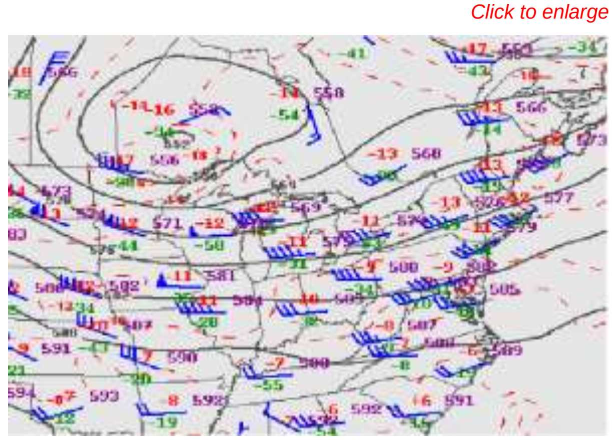

Figure 4 is the 500 hPa (around 20,000 feet above ground level) upper air analysis on 16 July 2009 at 12 UTC. This figure shows strong 500 hPa winds of 40 to 45 knots across the central Great Lakes into central New England.

In addition, the closed 500 hPa circulation just north of Lake Superior ejected several embedded disturbances in the winds aloft across our forecast area, which produced lift to increase thunderstorm development. Finally, the analysis showed cool temperatures ranging between -12c and -13c at 500 hPa, which produced conditions favorable for large hail and deep layer instability.

Pre-Storm Environment: Sounding Data

To better understand the entire column of air in terms of atmospheric stability and wind shear, we will examine the 18 UTC Albany, NY sounding on 16 July 2009. Figure 5 below shows several convective parameters associated with the sounding.

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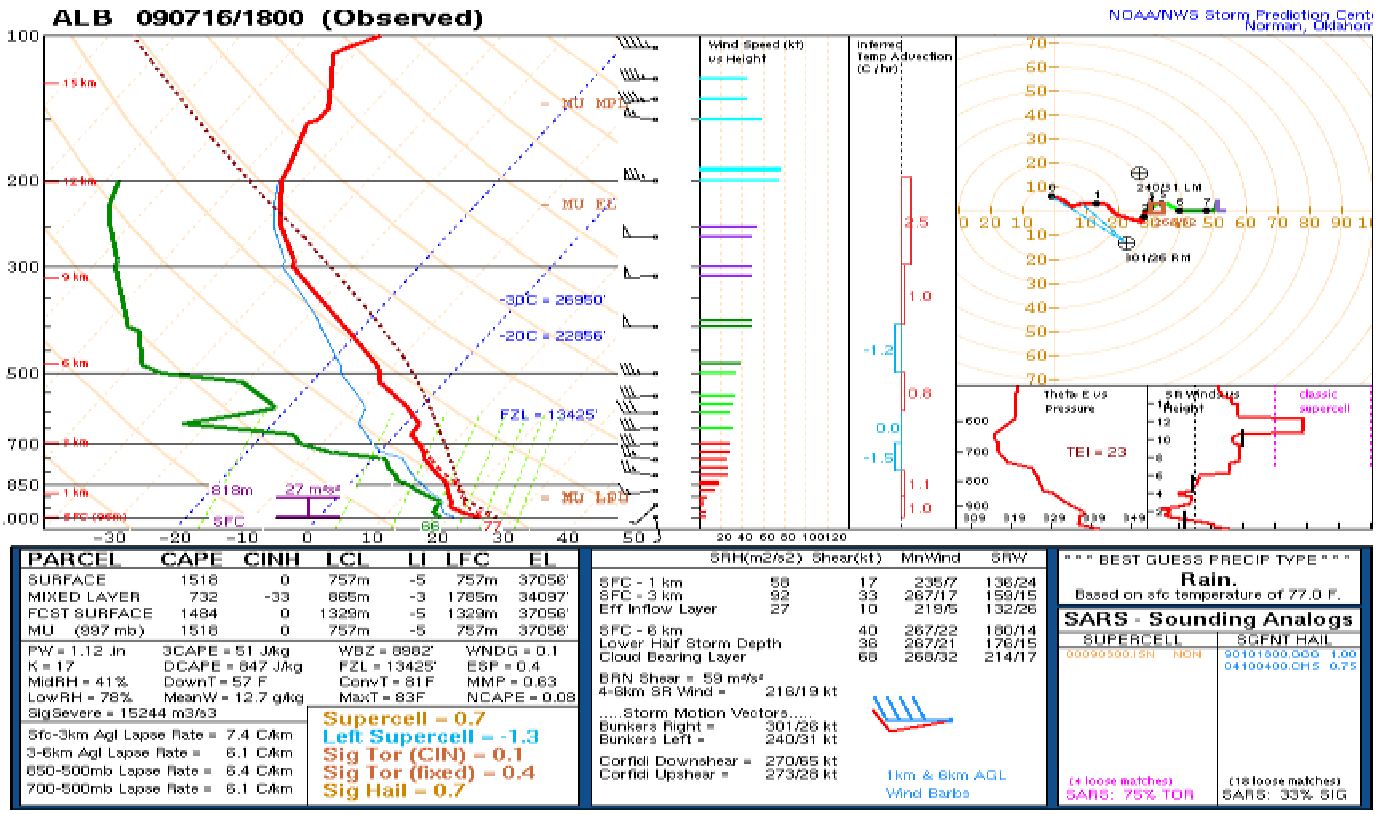

The non-routine 18 UTC July 16th rawinsonde observation at Albany, New York showed modest instability, along with moderate low to mid level winds helping to enhance the deep layer shear parameters across the region. Some shear parameters from the 18 UTC sounding included: surface to 3km bulk shear of 33 knots, surface to 6 km shear of 40 knots, and the Bulk Richardson Number of 59 m^2/s^2. These values were modest and would support organized convection, but also increased during the afternoon hours as strong jet stream winds aloft approached the region. Meanwhile, instability parameters included surface based Convective Available Potential Energy (CAPE) values around 1500 J/kg and Lifted Index values near -5C. However, lifted condensation levels were around 700 meters, which indicated plenty of low level moisture and low cloud bases. Greatest instability parameters were located over the WFO BTV CWA, associated with cooler temperatures aloft and better surface heating. Of additional interest was the supercell parameter of 0.7 off the 18 UTC Albany sounding, suggesting conditions favorable for right moving supercells, and the -1.3 value for left supercells indicating a potential for left moving cells. Click here for additional information on convective sounding parameters from SPC. Finally, a deep dry layer was noted between 700 hPa and 200 hPa in the 18 UTC Albany sounding (which can be observed by the large spread between the red temperature line and green dewpoint line through the atmosphere in figure 5 above). This dry air resulted in limited areal coverage of storms, but given the extreme instability the storms which did develop quickly became severe.

Pre-Storm Environment: Severe Weather Parameters

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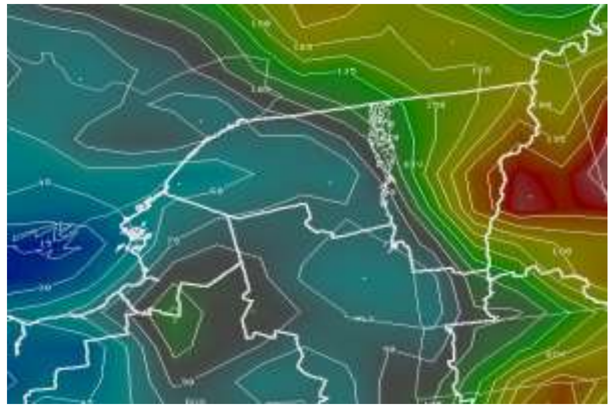

Meanwhile, along and south of the surface frontal boundary in central Vermont vertical shear and thermodynamic conditions become increasingly favorable for severe thunderstorms during the mid-afternoon hours on 16 July 2009. The Rapid Update Cycle (RUC) model indicated westerly surface to 6 km bulk shear values of 35-45 knots across central and southern VT by 20 UTC. This is consistent with the observed 40 knot value on the 18 UTC sounding at Albany. These values of deep-layer vertical wind shear are modest 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 fairly large.

The 18 UTC RUC 0-hr analysis indicated 0-3km SRH of 200 m2s-2 across central Orange County near the tornadic thunderstorm. (See figure 6). These values are typically sufficient for tornado production with supercells. The model derived values are consistent with the 18z Albany sounding which showed 0-1km SRH of 58 m2s-2 and 0-3km SRH of 90 m2s-2 respectively. However, the stronger values were located north of Albany. It is noteworthy that values of deep-layer shear and SRH rose significantly in the Albany soundings between 18 and 00 UTC as wind fields generally increased across eastern New York and central/southern Vermont (e.g., observed 0-3km SRH rose from 90 to 169 m2s-2 in 6 hrs).

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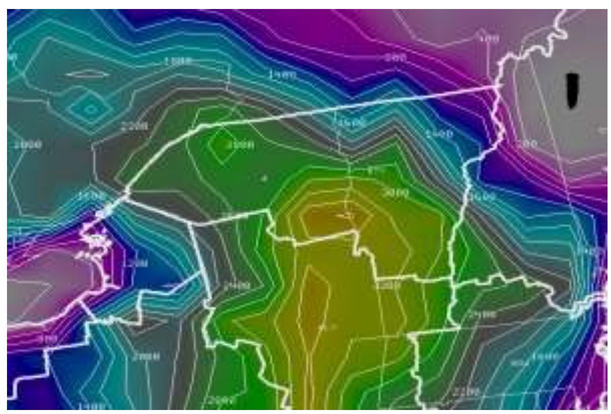

By 19 UTC CAPE had increased to around 2500 J/kg near Montpelier and 2800-3300 J/kg across portions of Essex County NY and Rutland County VT per LAPS 0-hr analysis. See figure 7 for LAPS CAPE analysis. There existed a sharp instability gradient collocated with the surface front across north-central Vermont. The extreme potential instability south of the front was aided by insolational heating (surface temperatures in the low to mid 80s) and southerly winds of 10-15 knots.

This resulted in 65-69F surface dewpoints streaming northward across the upper Hudson Valley of New York and the southern and central sections of Vermont. Given the modest deep-layer shear in place, these values of CAPE were sufficient to support severe thunderstorms. The observed 18 UTC CAPE at Albany was 1500 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 5.6 C/km at 12 UTC, to 6.1 C/km at 18 UTC.

Pre-Storm Environment: Surface Analysis

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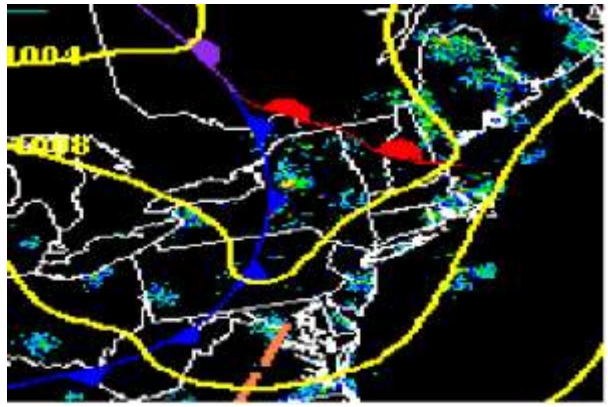

The surface map on 16 July 2009 showed a complex setup across northern New York as well as central and northern Vermont. The features included a warm front lifting across central Vermont at 18 UTC, while a strong cold front was approaching the Saint Lawrence Valley. Figure 8 shows the 18 UTC surface analysis on 16 July 2009. The warm front enhanced low level shear parameters with winds from the southeast ahead of the front across northeast Vermont and from the south to southwest across the Champlain Valley and southern Vermont south of the boundary.

In addition, this boundary helped to separate the very warm moist unstable air mass with CAPE values approaching 3000 j/kg across southern Vermont, from the cooler/drier air mass across northeast Vermont with CAPE values around 800 j/kg. This east west orientated boundary along with the approaching cold front created favorable surface conditions for severe thunderstorm development.

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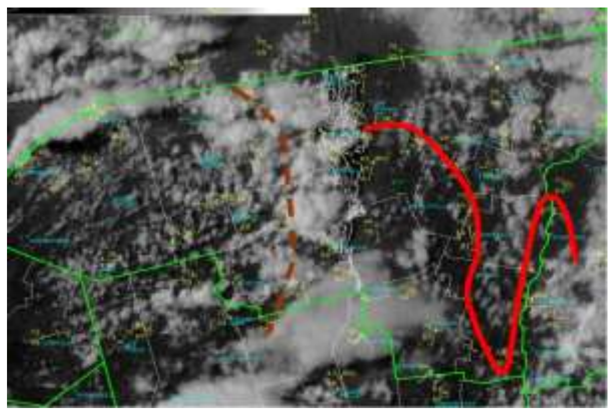

Figure 9 shows the visible satellite image at 18 UTC along with the position of the surface warm front and pre-frontal trough across our CWA. The pre-frontal trough located over the northern Adirondack Mountains interacted with a very unstable air mass across the Champlain Valley to help enhance strong to severe thunderstorms.

When these storms approached the surface warm front draped across central and eastern Vermont, the storms became better organized with rotating updrafts capable of producing tornadoes and large hail.

Pre-Storm Environment: Mesoscale Analysis

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The meso analysis supported model fields showing a very unstable atmosphere across our forecast areas with surface based CAPE values approaching 3000 j/kg. In addition to this extreme instability, modest 30 to 40 knot unidirectional deep westerly shear was present, making for environmental conditions favorable for line segments or mini supercells. Furthermore, the north south orientation of the Champlain Valley and east west warm frontal boundary helped enhance the low level turning of the winds. These factors combined with the instability parameters created a local environment favorable for supercells.

Click here for Mesoscale Discussion #1576 from SPC issued around 15 UTC. Figure 10 shows the Mesoscale Discussion graphic #1575 from SPC issued at 15 UTC. This image shows the warm front located across eastern New York quickly pushing north toward the Burlington forecast area. Very limited instability was present across our CWA at 15 UTC due to clouds and temperatures only in the 60s. Surface heating from increasing amounts of sunshine helped to warm temperatures well into the 70s and lower 80s by early afternoon on July 16th. Finally, figure 10 shows a surface cold front (blue triangles) approaching our western forecast area.

At 20 UTC on July 16th SPC issued another mesoscale discussion (click here for MCD #1583) to mention the strong to severe weather threat that continued across the region. In addition, vertical wind profiles off the KCXX radar showed the 0 to 6 km wind shear had increased to between 35 and 50 knots. Furthermore, the surface based CAPE values were between 2000 and 3000 J/kg across our CWA which made conditions very favorable for large scale organized severe thunderstorms, with supercell characteristics and rotating updrafts.

Click here for the area forecast discussion (AFD) from WFO BTV, highlighting the potential for severe thunderstorms and the potential for some rotating storms, especially across southern Vermont. The AFD highlighted the potential for isolated to scattered severe storms, but noted that the overall areal coverage would be limited due to a deep dry layer between 700 hPa and 500 hPa. In addition, the AFD highlighted the extreme instability with LAPS showing CAPE values around 2500 j/kg along with a VGP axis of 0.25 to 0.35 across central/southern Vermont. VGP is a severe weather parameter that combines shear and instability to determine the potential for severe storms with rotation. VGP values greater than 0.25 are favorable for tornadic cells. Click here for a VGP definition from SPC.

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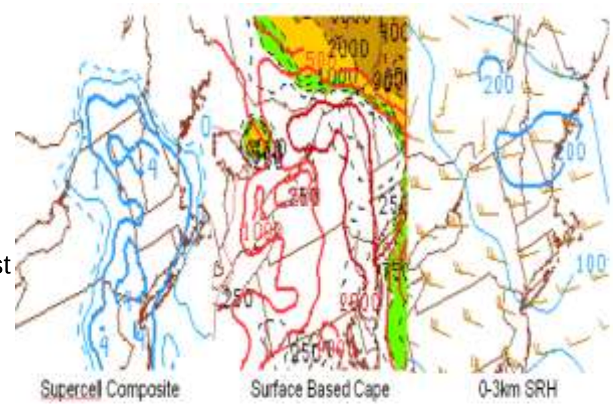

Figure 11 shows several severe weather parameters from the RUC analysis at 18 UTC on July 16th. The image at the left shows a plot of the supercell composite index (click here for a detailed description of supercell composite index). Values greater than 1 suggest that if thunderstorms develop, right moving supercells are possible.

The middle image shows the RUC surface based CAPE values, which shows a strong north to south gradient across our forecast area. The final image at the right shows 0-3km Storm Relative Helicity (SRH) (Click here for a definition of 0-3km SRH), along with the expected storm motion in the brown colored wind flags.

Radar Analysis

In this section we will discuss in-depth radar signatures and the associated reflectivity, velocity, storm relative motion (SRM) and other radar products used by forecasters here at the NWS BTV. We will be investigating two supercell thunderstorms very closely. The first storm will be a left moving storm, which tracked from Willsboro, New York across Lake Champlain through South Burlington and into Westford, Vermont, where the state's largest hail stone ever occurred. Meanwhile, the second storm we will review is a tornadic supercell which tracked from the central Vermont Mountains into western and central Orange County, and then into western New Hampshire.

Click to enlarge

Figure 12 shows a radar mosaic composite reflectivity loop from 19 UTC to 23 UTC on July 16th. Note early in the frames strong thunderstorms developing over the Eastern Adirondack Mountains in New York. These storms tracked east into the Champlain Valley and intensified as they encountered increased levels of instability.

The cluster of storms across Essex County, New York moved into southern Chittenden County, Vermont by early evening, and then split. One very intense cell moved northeast toward Westford, while the other cell moved southeast and re-organized across southern Washington and northeast Addison Counties before moving into western and central Orange County.

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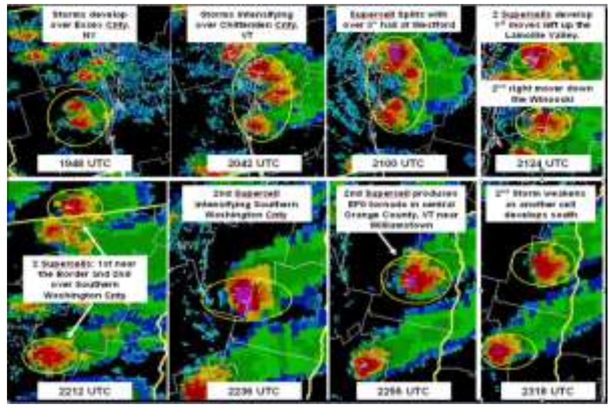

Figure 13 shows the storm evolution across our CWA on July 16th. The storms first developed across the higher terrain of the eastern Adirondack Mountains, then intensified as they reached the Champlain Valley, producing nickel-sized hail in South Burlington. The storms then continued to grow and split into two separate cells.

The 1st cell moved across northeast Chittenden County, Vermont producing over 3" diameter hail at Westford, and then tracked into the Lamoille River Valley before crossing the international border. Meanwhile, the 2nd storm split and turned right down the Winooski River Valley, then crossed the central Green Mountains and produced an EF0 tornado near Williamstown, Vermont along with plenty of hail. This storm continued to track southeast toward NH, while a third supercell developed over northern Rutland County and tracked east into western Windsor County. Figure 13 below shows the radar reflectivity evolutions of the supercells, which impacted our CWA on July 16th.

Radar Analysis: Westford Vermont Storm

In this section we will closely examine the storm which produced the Vermont State record for largest hail stone ever recorded. This investigation will include radar reflectivity cross sections, a product used to determine hail in a storm called VIL (Vertically Integrated Liquid), and a brief discussion on storm top divergence.

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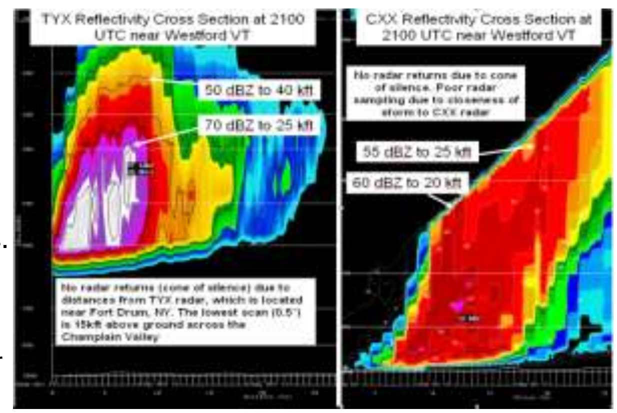

Figure 14 shows two reflectivity cross sections at 21 UTC near Westford, Vermont. Note the deep and very strong reflectivity core of 70 dBZ above 25kft from the TYX radar near Fort Drum NY, which indicates the potential for very large hail. In addition, 50 dBZ to 40 kft suggests very strong updrafts associated with this supercell, which makes good sense given the extreme instability. Remember, the warmer and moist an air mass is the quicker air can rise and produce strong to severe thunderstorms.

Click here for a diagram and explanation of the cone of silence and impacts on data sampling, especially with storms closest to the radar. In figure 14 the image at the left is from the TYX radar with no dBZ returns below 20kft due to elevation scan of the lowest slice from the radar. Meanwhile, the image at the right shows the CXX radar, with no dBZ returns above 20 kft due to the closeness of the storm to the Colchester, Vermont radar.

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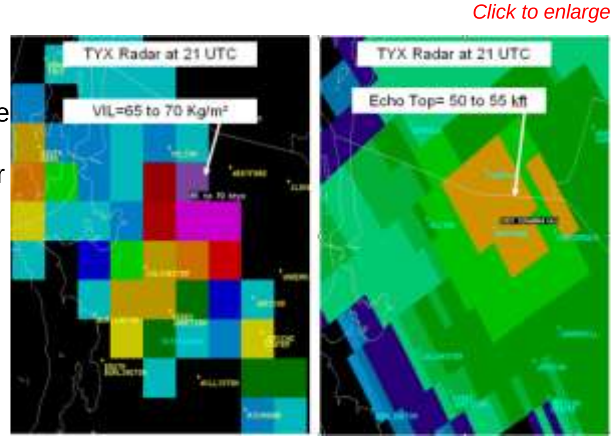

Figure 15 above shows the VIL image (left) and echo top (right) from the record hail producing storm near Westford, Vermont. Click here for a detailed definition of VIL. The VIL value for this storm was 65 to 70 Kg/m^2 with an echo top of 51 kft, which created a VIL density of 4.37 g/m^3, indicating hail greater than 1 inch is likely.

Click here for a definition on VIL density. Furthermore, the storm top divergence associated with this storm was between 75 and 80 knots, which indicated the potential for strong updrafts and large hail.

Radar Analysis: Williamstown Vermont Tornadic Storm

In this section we will review the tornadic supercell which developed across northeast Addison County, and tracked southeast across southern Washington county before moving into western and central Orange County. We will review several low level reflectivity images along with some storm relative motion (SRM) products to display the cyclonic storm rotation.

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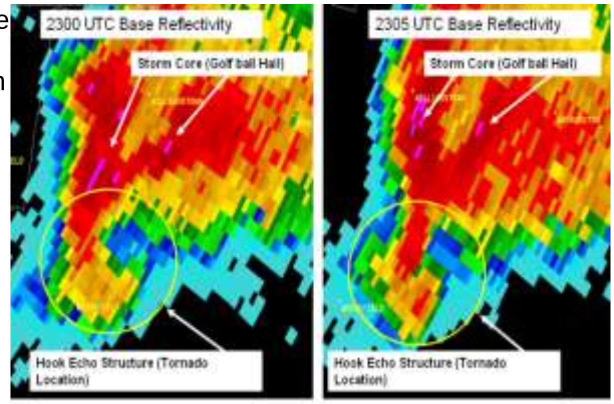

Figure 16 shows the 0.9° elevation base reflectivity slice from the CXX radar in Colchester, Vermont at 23 UTC. This base reflectivity clearly shows a well defined hook like structure, which is closely associated with a tornadic producing supercell. In addition, the tight reflectivity gradient on the southwest flank of the storm and cyclonic looking nature to the reflectivity structure supports the potential for a tornadic producing thunderstorm. Otherwise, the stronger reflectivity returns (deep red and purple colors) denote areas of large hail (this supercell produced golf ball size hail near Williamstown, VT).

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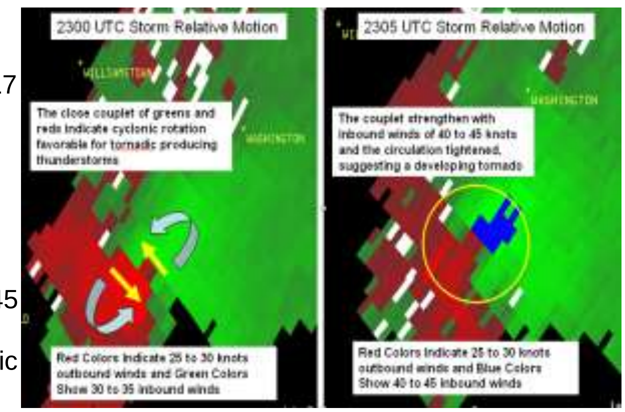

The next radar product we will examine is the storm relative motion (SRM) from the CXX radar. This is used to determine if the storm is rotating along with the strength of rotation. Figure 17 below shows the SRM product from the tornadic producing thunderstorm near Williamstown, Vermont.Figure 15 above shows the VIL image (left) and echo top (right) from the record hail producing storm near Westford, Vermont.

Figure 17 shows the cyclonic circulation strengthening from 23 UTC to 2305 UTC based on increased inbound winds of 40 to 45 knots (blue color). The close couplet of green and blue inbound velocities and red outbound velocities indicate moderate cyclonic rotation favorable for a potential tornadic thunderstorm. This tornadic storm had a persistent mesocylone detected by radar. However, no tornadic vortex signature (TVS) was indicated due to impacts of terrain on data sampling. Furthermore, this storm had a low level circulation of 57 knots with low level shear from the radar's Vr Shear tool of 0.35 to 0.45/Sec. This suggested a 35 to 45% chance of tornado formation. A moderate mesocyclone was indicated by radar with values between 35 and 40 knots that extended through 10 kft. Click here for TVS and Mesocylone definitions along with a mesocylone chart. This particular thunderstorm produced a weak EF0 tornado several miles south of Williamstown, Vermont, which was confirmed by the NWS storm survey.

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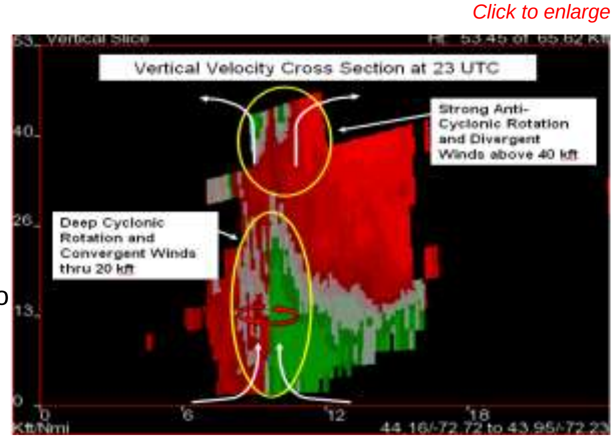

Figure 18 shows a vertical velocity cross section of the tornadic thunderstorm near Williamstown, VT at 23 UTC on July 16th. This cross section indicates the very good development and organization this particular supercell exhibited.

For example, the storm had deep convergence through 20 kft with cyclonic rotation, while above 40 kft the storm had excellent storm top divergence which helped to ventilate the storm and enhance the updraft. The total storm top divergence was close to 100 knots. This well organized supercell continued to track across central Orange County, then crossed the Connecticut River Valley and moved into New Hampshire where severe weather reports were observed.

Event Summary

This significant severe weather event featured over 20 reports of severe weather, which included a confirmed EF0 tornado and a record breaking hail stone which measured over 3 inches in diameter. In addition to the tornado and large hail, several reports of downed trees and power outages were reported. In total 16 warnings were issued, with 14 being severe thunderstorm warnings and 2 being tornado warnings. The average lead time was 20 minutes, with a probability of detection (POD) around 90%. The following images are pictures taken from our tornado damage survey near Williamstown, Vermont and of the record breaking hail stone in Westford, Vermont.

In addition, figure 19 shows the damage path caused by the EF0 tornado, with the red shading signifying winds of 40 to 50 mph and the white shading indicating winds of 55 to 75 mph.

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