The 2011 Pre-Memorial Day Severe Weather Outbreak and Flash Flood Event across the North Country

Part I: Introduction

On 26 May 2011, the first significant severe weather outbreak of the 2011 season occurred, along with devastating flash flooding across portions of northern New York and much of central and northern Vermont. A very warm and moist air mass was in place across most of the North Country with temperatures in the 80s and surface dewpoints in the mid to upper 60s. This very unstable environment along with a stationary front draped across the region helped to produce strong to severe thunderstorms across the North Country during the afternoon and early evening hours on 26 May 2011, which transitioned into a significant flash flood event during the overnight hours.

This severe weather event included numerous reports of severe and damaging thunderstorm winds of greater than 60 mph, along with several report of large hail, with baseball size hail reported near Duxbury, Vermont. Furthermore, the thunderstorms were accompanied by very heavy rainfall amounts of 3 to 5 inches with localized radar estimates near 7 inches across central Vermont, which caused significant flash flooding. Many roads were washed out and several rivers reached moderate to major flood stage as a result of the heavy rainfall. Most of the severe weather reports were concentrated along and south of a Star Lake, New York to Canaan, Vermont line, associated with several long-tracked miniature supercells, which continued into New Hampshire and Maine. A supercell is a thunderstorm that is characterized by the presence of a mesocyclone; a deep, continuously-rotating updraft. Supercells are the least common type of thunderstorm and have the potential to be the most severe. Supercells are often isolated from other thunderstorms, and can dominate sensible weather conditions up to 20 miles (32 km) away. As a result of scattered wind damage, National Weather Service (NWS) storm surveys were performed. We surveyed damage near Johnson, Plainfield, and Lunenburg, Vermont, and through the survey it was concluded that the damage was the result of straight-line thunderstorm winds.

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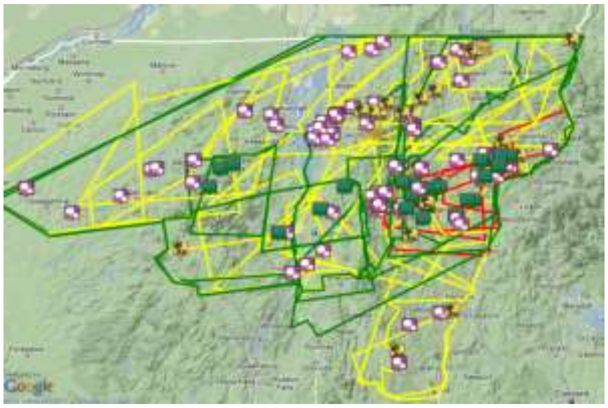

Figure 1 shows a Google Map display of the damaging wind, hail, and flash flooding which occurred during this event. The white ball icons indicate hail reports, the orange tree icons show areas of thunderstorm wind damage, and the green water icons represent areas of flash flooding. The yellow parallelograms in the image below show thunderstorm warnings, while the green colored boxes are flash flood warnings, and the red color polygons are where tornado warnings were issued. Click here for a complete listing of all severe weather and flash flood reports across Weather Forecast Office (WFO) Burlington, VT forecast area.

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

Storm Prediction Center Products (Day 1 Outlook, Probability of Tornados, and Mesoscale Discussions)

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From Figure 2 you can see the SPC Day 1 Outlook had the Champlain Valley and all of Vermont highlighted in slight risk for severe thunderstorms. Click here for the Day 1 text product issued by SPC. From SPC a slight risk implies well-organized severe thunderstorms are expected, but in small numbers and/or low coverage.

Depending on the size of the area, approximately 5-25 reports of 1 inch or larger hail, and/or 5-25 wind events, and/or 1-5 tornadoes would be possible. Also, click here to see how well the Storm Prediction Center did in the forecasting of slight risk across the eastern United States versus actual reports of severe weather.

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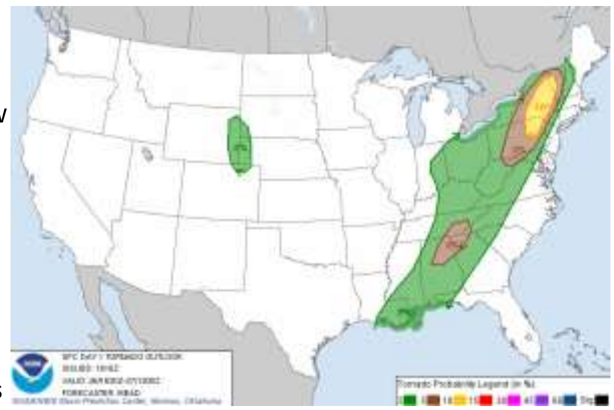

Meanwhile, Figure 3 shows the probabilistic forecast of severe thunderstorms producing tornadoes within 25 miles of a given point during the outlook period. A portion of northeastern New York and Western Vermont had a greater than 10% probability, which is relatively rare for the local area. On occasion we will see probabilistic forecasts of 30 or 45% chances of large hail or damaging thunderstorm winds across our forecast area.

The combination of a well defined surface boundary and very favorable turning of the winds in the middle to upper levels of the atmosphere, created conditions favorable for supercell thunderstorms capable of producing isolated tornadoes. Click here to view the meso-discussion issued by the SPC and the associated tornado watch box information graphic here.

Part II: Pre Storm Environment

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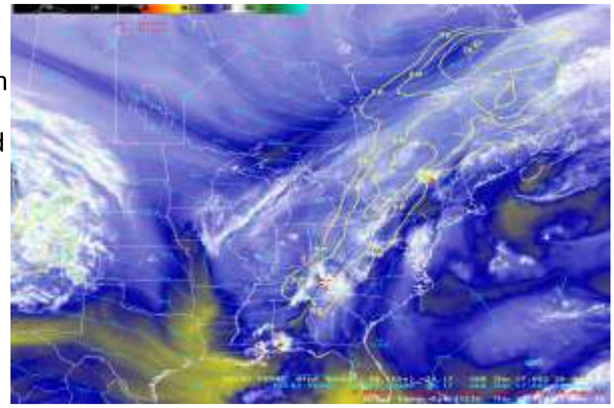

Figure 4 shows an eastern United States water vapor loop from 1640 UTC (Universal Time Constant: i.e., EDT plus 4 hours) to 2310 UTC on 26 May 2011, along with 500 hPa (20,000 feet above the ground level) heights (blue lines), wind speeds 50 knots or greater at 500 hPa (yellow lines), and 5 minute lightning (red).

This shows a strong short wave trough across the western Great Lakes and northern Mississippi River Valley, along with a right rear quadrant of a 500 hPa jet streak across western New York. These two features and associated cool pool aloft helped enhance upper level divergence and aided in the vertical development of thunderstorms. The closed height contours over the western Great Lakes into the Mississippi Valley, suggests very strong jet stream winds aloft, helping to promote strong updrafts for long-lived thunderstorms.

Upper Air Analysis

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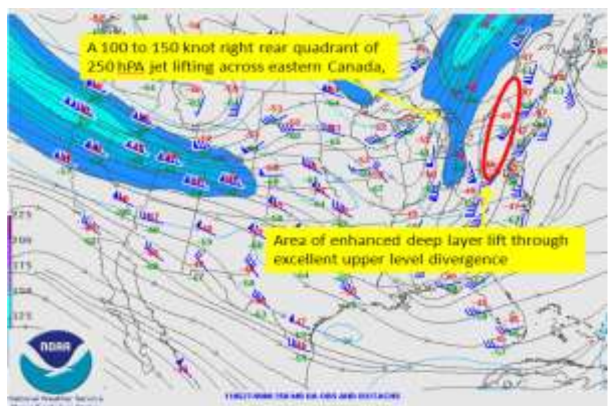

In this section we will discuss the pre-storm upper air conditions, which helped to produce severe weather across the Weather Forecast Office Burlington county warning area (CWA). A strong 130 to 150 knot anticyclonic curved 250hPa was lifting across eastern Canada and placing our region in a very favorable region of upper level divergence, which promoted deep thunderstorm convection.

Figure 5 shows the 250hPa (35,000 feet above the ground level) upper air analysis on 27 May 2011 at 00 UTC. Isotachs are lines of equal wind speeds (blue contours). Also shown are streamlines (black lines) and temperatures (red numbers in station plots).

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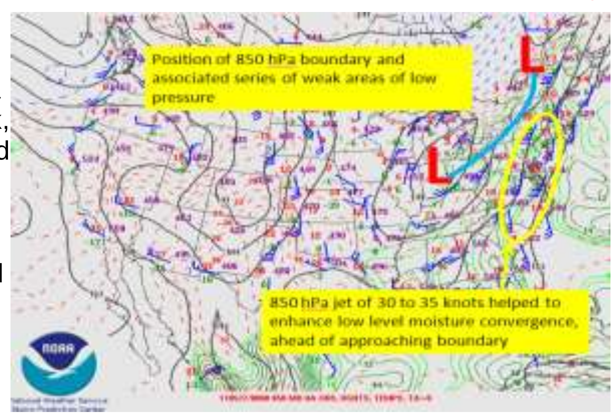

Figure 6 shows the 850hPa (~4,500 feet above the ground level) upper air analysis on 27 May 2011 at 00 UTC. This upper air analysis shows a strong boundary approaching northern New York, with a strong low-level jet of 30 to 40 knots ahead of this boundary.

This 850hPa jet helped to aid in low level moisture advection and transport of a very humid and warm air mass north into our region, along the approaching boundary. These features combined with the 250hPa divergence, helped produce an environment favorable for severe thunderstorms and very heavy rainfall.

Sounding Data

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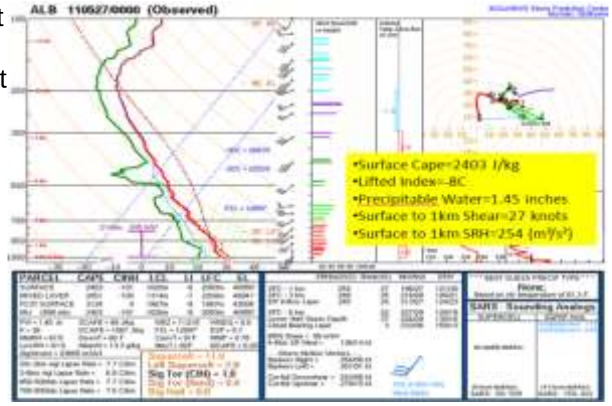

The 00 UTC May 27th rawinsonde observation at Albany, NY (Figure 7) shows high instability, and moderate deep-layer shear, due to the placement of the strong low to mid-level winds across central New York into southern Canada(as shown in the previous section). The combination of surface temperatures in the lower 80s and dewpoints in the mid to upper 60s created surface-based convective available potential energy (CAPE) values of 2403 J/kg, with a lifted index (LI) of -8C (Celsius). CAPE values greater than 1500 J/kg, suggest a moderately unstable environment, favorable for thunderstorm development. The large CAPE profile and very high equilibrium levels indicated thunderstorm tops would extend to 35,000 to 45,000 feet into the atmosphere, and be capable of producing severe winds or large hail, along with very heavy rainfall. The equilibrium level is the level at which the rising parcel equals the actual air temperature at that given height, and results in the rising parcel now becoming stable; it no longer accelerates upward.

In addition, the Albany sounding showed surface to 1km shear of 27 knots. This shear was a result of the approaching boundary and the embedded low level jet. 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, which was present across our region due to the jet stream winds aloft. Finally, the 00 UTC Albany sounding showed a precipitable water value of 1.45 inches, which suggests the potential for thunderstorms to produce very heavy rainfall. Precipitable water is the depth of the amount of water in a column of the atmosphere if all the water in that column were precipitated as rain. Values greater than 1.2 inches, suggests a greater potential for heavy rainfall, especially during the summertime.

Severe Weather Parameters

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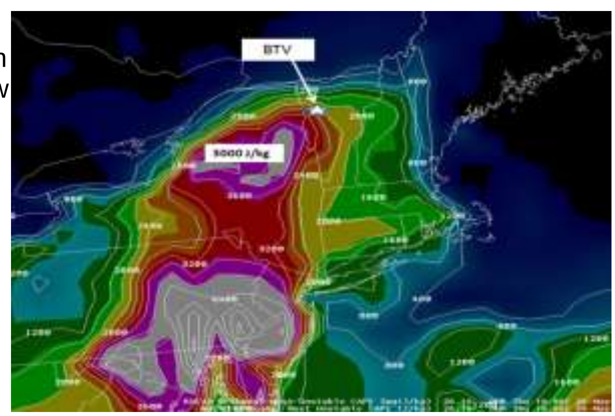

Figure 8 shows the 19 UTC RUC (Rapid Update Cycle) CAPE values across the North Country on 26 May 2011. The yellow color-filled image below indicates CAPE values greater than 2000 J/kg and suggests moderate instability.

The RUC analysis indicated a maximum area of CAPE; across the northern Adirondacks into central and southern Vermont, with values between 2000 J/kg and 3000 J/kg. The potential instability was contributed to by insolational heating (surface temperatures in 80s), and surface dewpoint values in the mid to upper 60s, while southerly winds were 10 to 20 mph.

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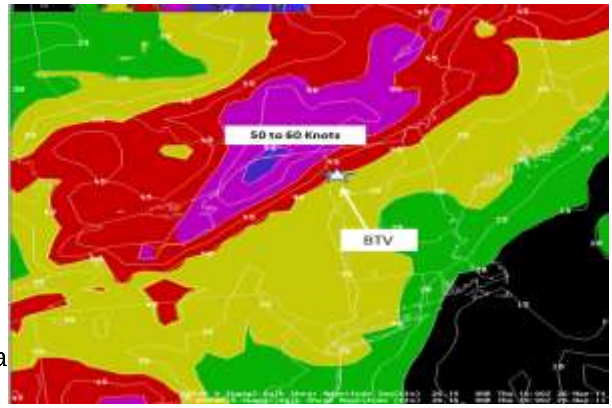

The surface to 3 km bulk shear (Figure 9) from the RUC at 19 UTC on 26 May 2011 revealed an area of increasing shear approaching the region from the west across the Saint Lawrence Valley. The analysis showed values between 50 and 60 knots (pink color fill in Figure 9) across northern New York at 19 UTC.

These strong values support organized and persistent thunderstorms, with a greater potential for supercells, capable of producing large hail and damaging winds. This increased shear was a result of the approaching mid/upper level trough and associated embedded mid to upper level jet streak, which was highlighted in the 12 UTC upper air data.

Precipitable Water

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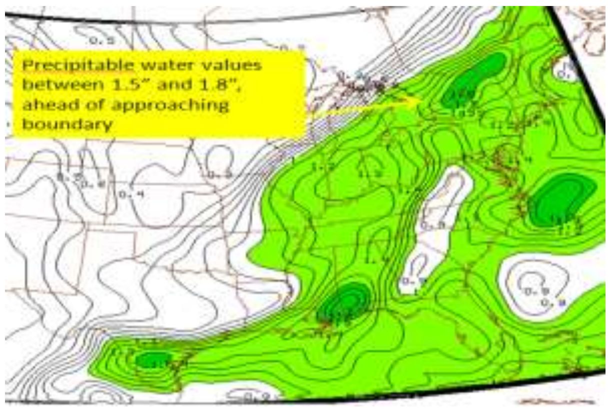

Figure 10 shows the RUC 40-km precipitable water values across the northeast United States at 18 UTC on 26 May 2011. This analysis shows values between 1.5" and 1.8" pooling ahead of a surface boundary approaching the Saint Lawrence Valley, and provides an excellent indicator that thunderstorms would have the potential to produce very heavy downpours.

The deep southerly flow ahead of the approaching surface feature and mid/upper level trough helped to transport this very moist/humid air mass into our region. As a result, thunderstorms developed, which produced hourly rainfall rates of 1 to 2 inches across the region, and caused significant flash flooding.

Part III: Radar Analysis

In this next section we will discuss in-depth radar signatures and provide analysis for several storms, which produced significant wind damage and large hail across the region. In addition, we will examine closely the strong rotating supercells across eastern Vermont and try to explain why no tornados were produced. Other areas we will examine are the straight-line wind damage from Johnson to Island Pond Vermont, and the baseball size hail in South Duxbury, Vermont. We will first show the northeast radar mosaic (figure 11 below) of the widespread areal coverage and intensity of the storms, followed by a detailed examination of individual storms, with reflectivity and velocity cross-sections, vertical integrated liquid (VIL), and low-level plain view storm relative velocity displays.

Radar Mosaic Overview

Click to enlarge

Figure 11 is a Northeast regional composite reflectivity mosaic from 1806 UTC to 2354 UTC on 26 May 2011, along with surface observations plotted in white. This loop shows the widespread areal coverage and intensity of the storms from eastern Lake Ontario into much of northern New York and Vermont during this severe weather outbreak.

In addition, the radar loop shows multiple long-tracked supercell thunderstorms across the region, several of which affected the WFO BTV forecast area. The brighter yellows, reds, and purple colors in the radar loop indicate very strong thunderstorms with intense rainfall rates, along with the capability of producing severe hail.

Caledonia/Orange Counties (Straight Line Wind)

The first storm we will examine will be the central and southern Caledonia County supercell, which was very well organized with some low-level rotation. However, a NWS storm survey showed no tornado developed, only straight-line wind damage occurred. Given the 60 to 70 mile distance from the radar, and the lowest two elevation scans being blocked by the Green Mountains, data quality in the lowest several elevation scans is very limited. This makes storm interrogation very difficult across eastern Vermont and parts of the Northeast Kingdom.

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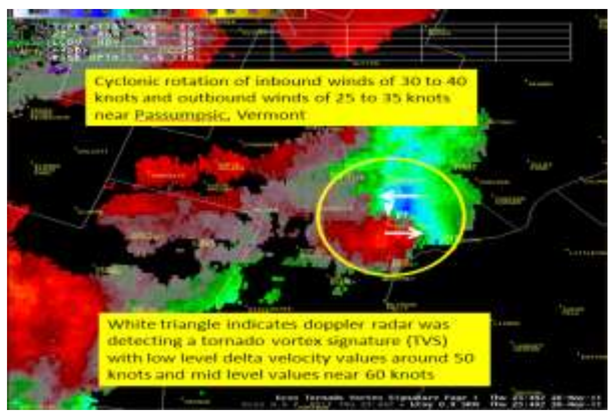

Figure 12 shows the KCXX 0.9° storm relative velocity at 2349 UTC on 26 May 2011, with the Doppler radar tornado vortex signature indicated by a white triangle. The radar indicated a broad cyclonic (counter-clockwise) circulation with inbound velocities of 30 to 40 knots and outbound winds of 25 to 35 knots.

The TVS was indicating low level delta velocities (LLDV) of 50 knots and mid level delta velocities (MDV) of 56 knots at this time, which is relative strong. As the distance from the radar increases, the beam spreads out, making tight low level couplet circulations difficult to detect, and much broader than they may appear in reality.

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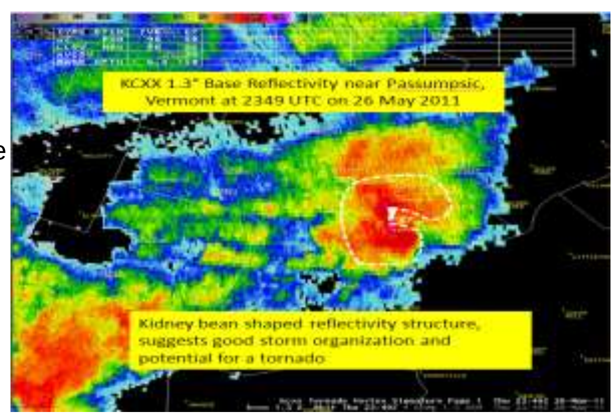

In addition, to a strong rotational signature, the storm near Passumpsic, Vermont also had a "kidney bean" like reflectivity structure. Figure 13 shows this signature very well, which represents good storm organization, and the potential for the storm to produce a tornado.

However, based on a damage survey, only straight-line damaging winds occurred from eastern Washington County into extreme southern Essex County, Vermont with this supercell. The brighter red and purple cores show a very intense storm core, which produced very heavy rainfall and some golf ball size hail near Lunenburg, Vermont.

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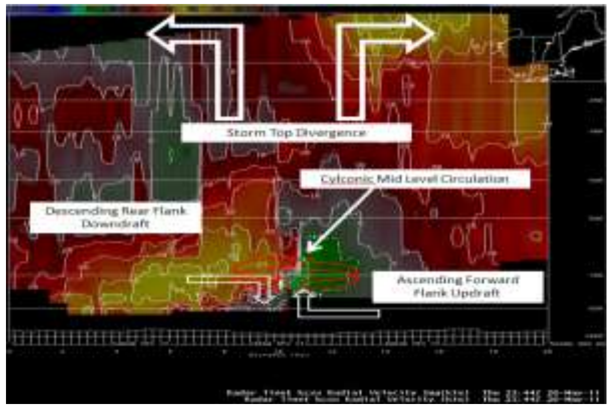

Figure 14 shows a vertical cross section of velocity from the KCXX at 2344 UTC on 26 May 2011. This shows the limited vertical rotation of the storm near Passumpsic, Vermont. However, the storm did have a storm top divergence signature of70 to 80 knots, along with a descending rear flank downdraft velocity of 40 to 50 knots.

A mid level cyclonic couplet was present around 700 hPa, but the vertical depth of rotation was limited. Due to the distance away from the radar, velocity data is very poor below 4500 feet above ground level.

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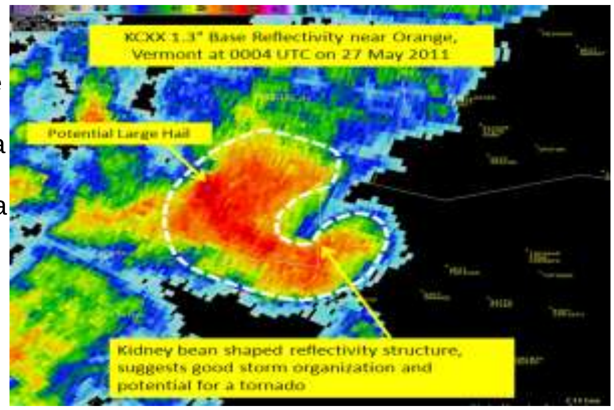

Figure 15 shows a well defined kidney bean reflectivity structure near Orange, Vermont on 27 May 2011 at 0004 UTC. This reflectivity structure suggests the potential for a tornado, within the hook like structure. This storm developed along a surface boundary, which helped to enhance the low-level turning of the wind fields and provided a storm-scale environment favorable for supercells capable of producing a tornado.

However, no tornado was cited and the survey determined that the damage resulted from straight-line winds. Also, 1 inch hail was reported near Barre, Vermont. We see many times in the past several years good radar signatures of a possible tornado, but find the broad circulation at 4000 to 6000 feet above the ground is unable to reach the surface and many times quickly weakens across the higher terrain of the Green Mountains.

Washington County near South Duxbury, Vermont (Baseball Hail)

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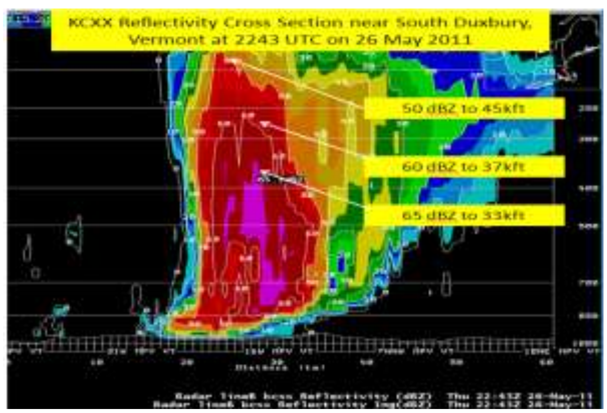

The next supercell thunderstorm we will examine tracked from near Duxbury to Barre to northern Orange County, Vermont on the evening of May 26th and produced baseball size hail in South Duxbury and several areas of thunderstorm wind damage, along with rainfall amounts of 1 to 3 inches. We will show a reflectivity cross section to determine the vertical depth of the storm, along with a vertical integrated liquid product, which is a good indicator of the severity of the hail. Figure 16 shows a vertical reflectivity cross section taken near South Duxbury, Vermont on 26 May 2011 at 2243 UTC. This cross section shows a very deep and well-developed supercell thunderstorm with a storm top up to 50,000 feet. In addition, the reflectivity structure showed 50 dBZ to 45,000 feet and 60 dBZ to 37,000 feet, indicating very strong storm updraft capable of producing very large hail. Also, note the weaker 20 to 30 dBZ returns on the upper right part of the image, representing forward flank anvil and suggesting very strong jet stream winds aloft, helping to enhance upper level divergence over the storm. These factors all came together, along with a moist and unstable environment to promote supercell thunderstorms capable of large hail and damaging winds on the afternoon and evening of May 26th.

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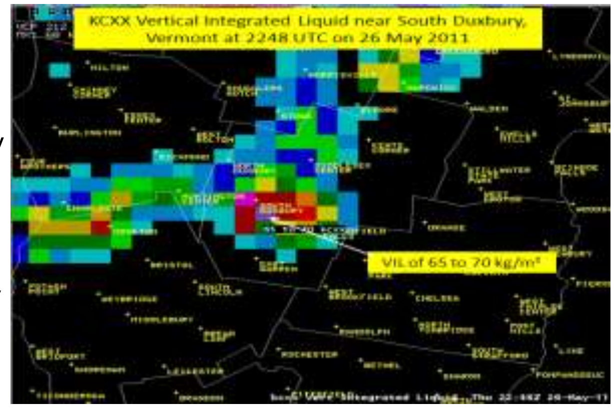

Figure 17 shows the KCXX Vertical Integrated Liquid (VIL) at 2248 UTC on 26 May 2011. VIL is an estimate of the total mass of precipitation in the clouds. The measurement is obtained by observing the reflectivity of the air as obtained by radar. This measurement is usually used in determining the size of hail, the potential amount of rain under a thunderstorm, and the potential downdraft strength when combined with the height of the echo tops. When VIL values quickly fall, it may mean that a downburst is imminent, resulting in the weakening of the storm′s updraft and the storms inability to hold the copious amounts of moisture/hail within the storm's structure and a greater potential for the storm to produce damaging winds. Figure 17 shows VIL (pink/purple color) values between 65 and 70 kg/m^2 near South Duxbury, Vermont. This indicates a very well developed updraft, capable of producing large hail and damaging winds, especially when the storm collapses and weakens, which occurred between South Duxbury and Northfield, Vermont on 26 May 2011.

Lamoille County Storm near Johnson, Vermont (Damaging Winds)

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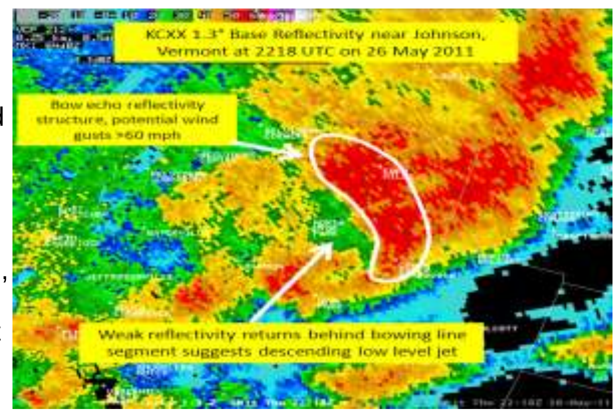

In addition, to the supercell thunderstorms which occurred across our region on 26 May 2011, further north across central and northern Vermont, a bow-like line segment developed and created damaging straight-line winds from near Johnson to North Hyde Park.

Figure 18 is the KCXX 1.3° base reflectivity near Johnson, Vermont at 2218 UTC on 26 May 2011, which clear shows a bow like reflectivity structure. The weaker 20 to 30 dBZ returns (light green) near North Hyde Park, Vermont suggests a descending rear flank downdraft jet is present and capable of producing damaging thunderstorm wind gusts of 60 to 70 mph, based on the velocity values.

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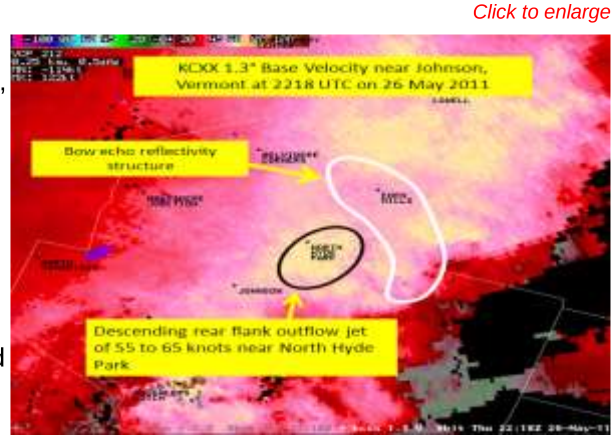

Figure 19 is the KCXX 1.3° velocity near Johnson, Vermont at 2218 UTC on 26 May 2011, which clearly shows the descending rear flank downdraft jet of 55 to 65 knots. The highest velocity values at this time were located near North Hyde Park, Vermont, just behind the bow like reflectivity structure.

Damaging winds did occur from this storm from Johnson, Vermont into North Hyde Park, and continued toward Island Pond as the storm raced northeast at 40 to 50 mph. Also, when storms move very fast, they have a higher potential to produce wind gusts greater than 60 mph, as a rule of thumb.

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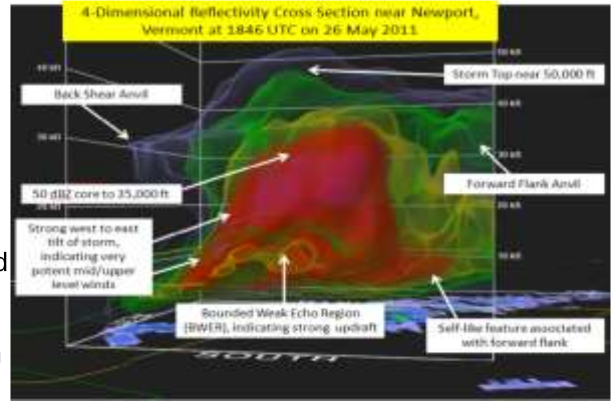

Figure 20 is a special 4-dimensional look into a supercell thunderstorm near Newport, Vermont on 26 May 2011 at 2218 UTC, using GR2Anlyst. This software program used by NWS meteorologists, shows the 4-dimensional structures of storms, and helps in the warning decision process.

This storm near Newport was very well organized with a defined Bounded Weak Echo Region (BWER), suggesting very strong updraft and the potential for large hail, especially when the storm collapses. This storm did produce 1 inch diameter hail near Newport, along with some gusty winds. Also, from Figure 20 below you can see a strong west to east tilt, suggesting very strong mid/upper level winds were impacting the storm and displacing the core of the downwind of the updraft. The storm top was near 50,000 feet, with both a forward and back anvil structure present, along with a >50 dBZ core to 35,000 feet.

Part IV: Hydrology

As the threat for severe thunderstorms dissipated on the evening of May 26th, our attention quickly turned to the potential for life-threatening flash flooding across the eastern Adirondacks into most of central and northern Vermont. The combination of a stationary boundary across the region and numerous thunderstorms training over the same areas, produced widespread rainfall amounts of 2 to 4 inches with isolated amounts over 6 inches in a 6 to 8 hour window. This rainfall in a short period of time caused extensive widespread flash flooding from Barre, to Saint Johnsbury, Vermont and many communities in between. Numerous roads and culverts were washed out and many residents and businesses received significant flood damage during the event, especially in the city of Barre. In addition, several rivers including the Winooski, Passumpsic, and Mad had very sharp rises and quickly went rose above flood stage.

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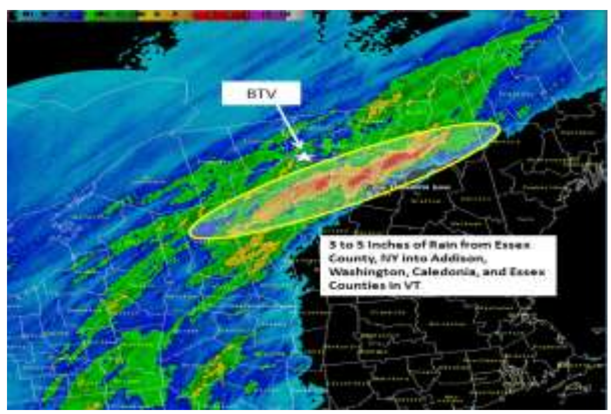

Figure 21 shows the 24 hour Northeast Mosaic storm total precipitation from 12 UTC on 26th to 12 UTC on 27 May 2011. The yellow area is storm total radar rainfall estimates of 2.5 to 5 inches, while the red suggests rainfall amounts between 5 and 7 inches.

From the image you can see the highest radar estimate rainfall occurred from Essex County, New York into Addison, Washington, Caledonia, Orange, and Essex Counties in Vermont during the event.

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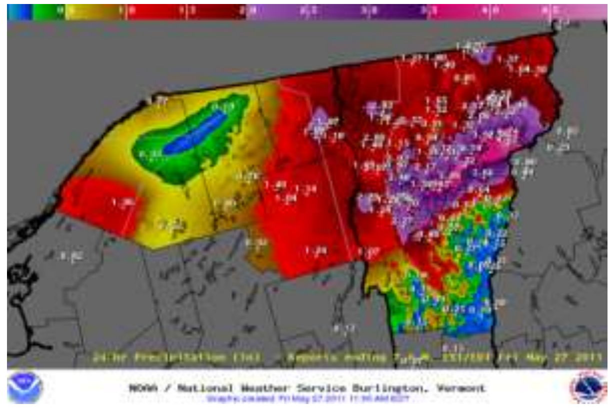

Figure 22 shows the 24 hour precipitation (inches) observed from 12 UTC on 26th to 12 UTC on the 27th of May across our forecast area. The highest official observation came from the Plainfield, Vermont Coop at 5.22 inches in 24 hours located in eastern Washington County, Vermont.

From the map you can see many locations receiving 2 to 4 inches (purple/pink) in the 24 hour period across most of central Vermont and parts of the Champlain Valley from the training thunderstorms. Click here for a complete listing of 24 hour rainfall reports across the region. A couple of the higher 24 hour rainfall amounts included 4.75 inches at the Saint Johnsbury Museum in Caledonia County, 4.15 inches 1 mile north of Northfield, and 4.06 inches in Danville, Vermont on 27 May 2011. This heavy rainfall in a short period of time associated with powerful thunderstorms caused major flash flooding across central Vermont.

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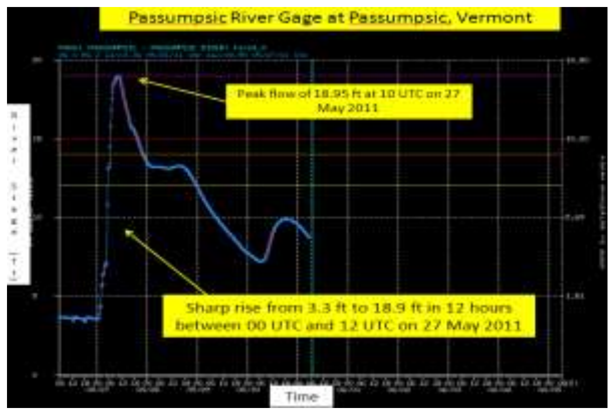

The heavy rainfall quick produced flash flooding and flowed into many of the streams and rivers across the region. Figure 23 shows the hydro graph on the Passumpsic River, at Passumpsic, Vermont. This clearly shows a significant rate of rise between 00 UTC and 12 UTC on 27 May 2011 at the gage of over 10 feet.

The gage started with a reading of 3.3 feet, but quick rose to a maximum reading of 18.95 feet at 10 UTC on 27 May 2011, which is just below major flood stage of 19 feet. At one point overnight, there was a rise of 11 feet in 3.5 hours. This sharp rise caused significant flooding in the Passumpsic River Valley during the event. Also, the hydro graph showed very sharp rises on the Mad River at Moretown, Vermont. In addition, the Winooski at Essex Junction reached flood stage during the event, which caused some flooding in the Winooski River Valley from Montpelier to Colchester, Vermont.

Part V: Conclusion/Pictures

The high instability values along with moderate deep layer shear produced an environment favorable for thunderstorm development during the afternoon and evening hours on 26 May 2011 across the WFO BTV forecast area. In addition, the amount of available moisture in the atmosphere and placement of the low-level and upper level jet features along with the presence of a stationary boundary, helped to produce vertically tall thunderstorms capable of very heavy rainfall. Several rounds of thunderstorms first developed across the Saint Lawrence Valley and northern Adirondack Mountains, and then tracked east into the Champlain Valley, then into central and northern Vermont. These long-tracked supercells produced large diameter hail at several locations across the North Country, along with numerous reports of trees and power-lines down, from winds up to 70 mph. The highest concentration of damage occurred from Johnson to Island Pond, Vermont, with another maximum area of damage in the South Duxbury to Plainfield to Lunenburg, Vermont areas. Meanwhile, the greatest flash flooding occurred from Barre to Saint Johnsbury, Vermont. The following pictures were taken by Scott Whittier from WFO BTV during a storm damage survey in the areas of maximum damage.


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