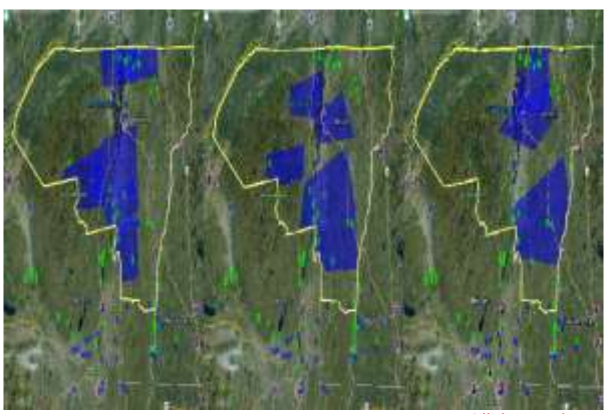
Heavy Precipitation Supercells of 29 May 2012

Part I: Introduction

On 29 May 2012, the first significant severe weather outbreak of the 2012 season occurred, along with major flash flooding across portions of central and northern Vermont and parts of the eastern Adirondack Mountains. 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 upper 60s to lower 70s. This very unstable environment along with a warm front draped across central Vermont helped to produce strong to severe thunderstorms across the North Country during the afternoon hours on 29 May 2012, which transitioned into a significant flash flood event during the late afternoon and evening hours.

This severe weather event included a confirmed EF0 (on the Enhanced Fujita Scale) tornado near Glover, Vermont, along with numerous reports of large hail and damaging thunderstorm winds. Click here for the public information statement, regarding the confirmed tornado. Hail up to baseball size was reported near Crown Point, New York and trees and power lines were down in Milton, Vermont from the powerful storms. Furthermore, the thunderstorms were accompanied by very heavy rainfall amounts of 2 to 4 inches with localized radar estimates near 6 inches across the southern Champlain Valley, which caused significant flash flooding. Many roads were washed out and numerous rivers and streams had sharp rises, as a result of the heavy rainfall. Click here for the local storm report, which shows the locations of the severe weather and flash flood damage.

Many of the severe weather and flooding reports were concentrated from the eastern Adirondack Mountains in northern New York into central and northern Vermont. These reports were associated with several long-tracked heavy precipitation supercells, which continued into parts of New Hampshire. Click here for a complete plot of all the severe weather reports on 29 May 2012 across the Northeast and Mid-Atlantic States. Figures 1 and 2 below show a Google background map with severe thunderstorm and tornado warning polygons and a plot of the associated severe weather reports on 29 May 2012 across the North Country. The green "H" represents severe hail reports one inch or greater in diameter, the blue "W" represents thunderstorm wind damage or gusts 58 mph or more, and the red "T" is the tornado touch down location in Orleans County, Vermont.



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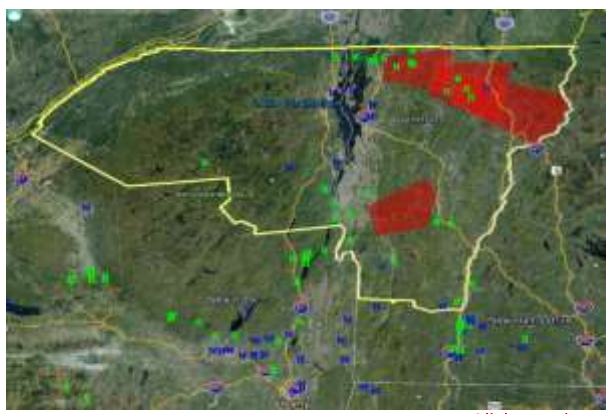

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Storm Prediction Center Products (Day 1 Outlook, Probability of Tornados, and Mesoscale Discussions)

The NOAA/NWS Storm Prediction Center (SPC)'s Day 1 Convective Outlook (not shown) on the morning of Tuesday May 29th indicated a "Slight Risk" of severe thunderstorms across the North Country. As the morning unfolded, it became increasingly clear that a significant severe weather event was likely. At that time, SPC issued a Mesoscale Discussion (MCD, not shown), a product used to call attention to a particular area of thunderstorm threat. MCDs are often issued when the SPC is considering Severe Thunderstorm and/or Tornado Watch products, and/or to alert forecasters of potential changes in upcoming Convective Outlooks. With this MCD, SPC chose to upgrade to a "Moderate Risk" of Severe Thunderstorms across portions of central and northern New York and extreme southwestern sections of Vermont. "Moderate Risk" forecasts in the North Country are rather infrequent (occurring perhaps once or twice per year). When such forecasts are issued, it often indicates the potential for a more enhanced severe weather threat.

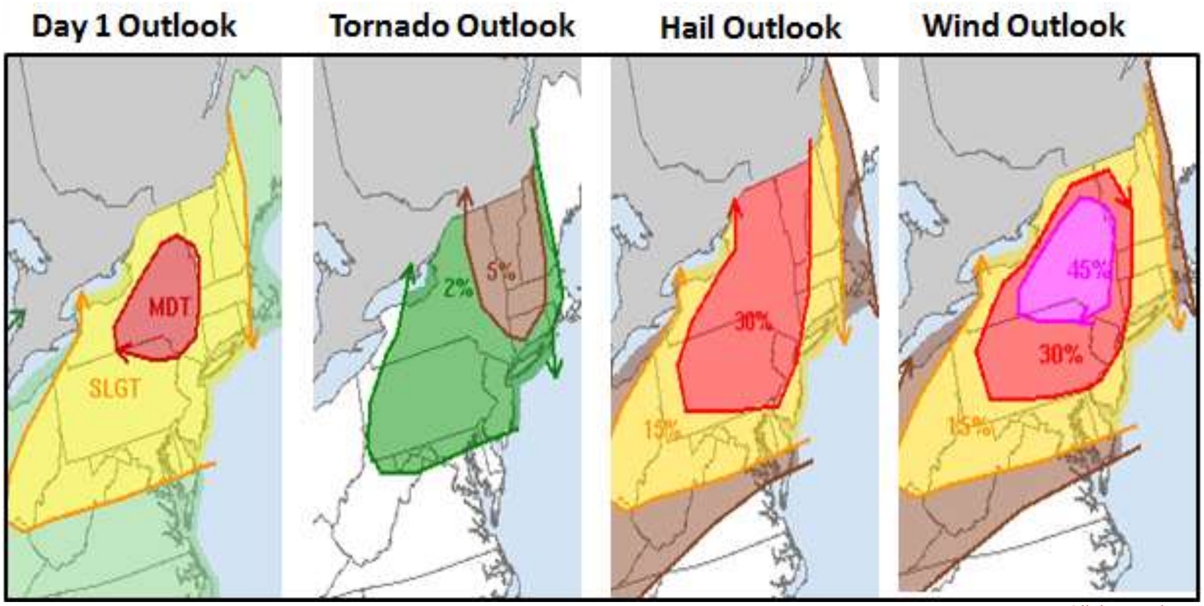

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Figure 3 above shows the early afternoon Day 1 Convective Outlook and the associated probabilities of tornadoes, damaging winds, and severe hail. The "Moderate Risk" area highlighted in the late morning Mesoscale Discussion is shown in the left-most panel, with a broad area of "Slight Risk" surrounding this area including much of New England. Tornado probabilities ranged between 2% and 5% -- with the 5% probabilities (shaded in brown) forecast for all of Vermont and the Champlain Valley region of eastern New York. This meant that as high as a 5% probability of tornadoes occurring with 25 miles of any point were expected in the 5% probability area. Severe hail probabilities were up to 30% across the entire North Country (i.e., there was a 30% probability of at least 1 severe hail report occurring within 25 miles of any point in the 30% probability area, shaded in red). The Severe Wind Outlook forecast called for 30% severe wind probabilities (red shading), though probabilities as high as 45% (indicative of a potential significant wind damage threat, purple shading) were forecast across north-central New York and into extreme southwestern sections of Vermont.

Shortly after the early afternoon Day 1 Convective Outlook was issued, the SPC issued a Tornado Watch for most of the North Country, effective through 9:00 PM local time. This is shown in Figure 4 below. At 17 UTC (12:00 PM local), SPC issued another Mesoscale Discussion, addressing areas in the Tornado Watch. The Mesoscale Discussion graphic is shown in Figure 5. SPC forecasters pointed to a region of more enhanced tornado threat extending along and north of the position of the surface warm front (shown by the red line with red half-circles in the graphic). In addition, surface winds enhanced by channeling effects in valley locations across central and northern Vermont helped to increase low-level wind shear that can be favorable for tornado formation.

Click to enlarge

Click to enlarge

Part II: Pre Storm Environment

One of the more interesting factors behind this severe weather and flash flooding episode occurred during the early morning hours of May 29th. Severe thunderstorms had initially developed across western Clinton and Essex Counties in New York as well as across central and northeastern Vermont. Hail up to half-dollar size (1.25" diameter) fell across parts of Washington and Windsor Counties in Vermont. However, thunderstorms "training" over the same locations resulted in 1-2 inches of rain across central and northeastern Vermont. These antecedent wet conditions would help set the stage for localized flash flooding later in the afternoon.

The early-afternoon surface map (not shown) showed a cold front stretched across much of eastern Ontario, with a warm front extending from western Quebec southeastward across north-central and northeastern Vermont. Afternoon temperatures in the mid-80s and dewpoints in the mid to upper 60s would result in the development of a large amount of instability (CAPE values ranging from over 3000 J/kg across northern New York to around 1000-2000 J/kg across most of Vermont) which led to the possibility of another round of severe thunderstorms by the afternoon.

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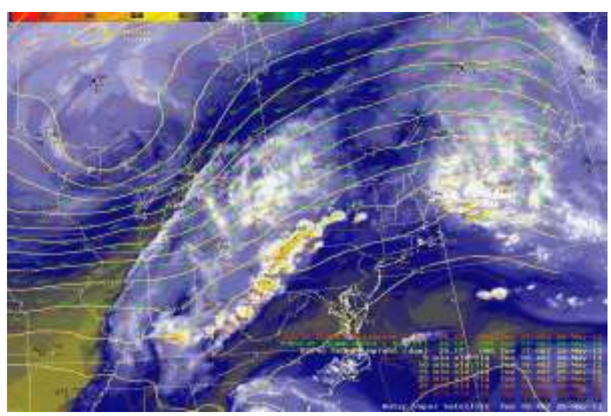

Figure 6 is a water vapor satellite imagery loop, with 500hPa heights (solid yellow lines), 500hPa wind speeds greater than 50 knots (dashed red lines) and 250hPa wind barbs greater than 50 knots (green wind barbs) from the Rapid Refresh forecast model. Observed lightning strikes are also shown to get a sense as to where the most intense thunderstorms are located. In the image loop, we see a potent upper-level shortwave trough over the northern Great Lakes, with an upper-level ridge located just off the coast of Massachusetts into the Gulf of Maine. Two upper-level jets are evident in the loop: one approaching southern Ontario, and the other located over northeastern Maine. These jets helped to enhance upper-level divergence over the thunderstorms themselves, and helped maintain the persistence of the thunderstorm updrafts by enhancing vertical wind shear through a deep layer of the atmosphere.

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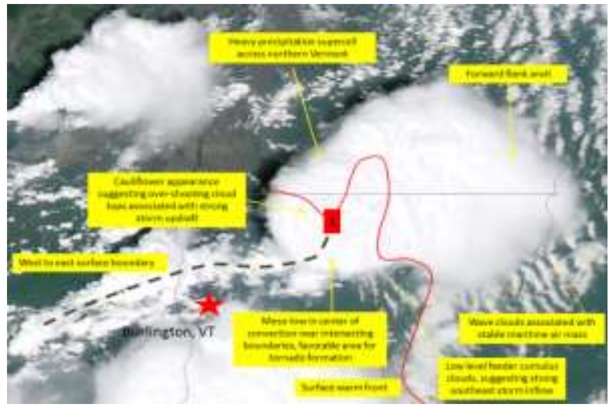

Figure 7 shows a high-resolution (250 meter) visible satellite image of the supercell thunderstorm that would go on to produce the EF0 tornado in West Glover, VT. The satellite image is taken from the MODIS Aqua satellite instrumentation platform at around 18 UTC May 29th. The high-resolution detail of the image illustrates several important details of the storm's structure and its near-storm environment. The cauliflower appearance in the cloud tops shows where the strongest updrafts are occurring, and in the center is an "overshooting top", which occurs when the strongest updraft are able to penetrate above the thunderstorm anvil and into the lower stratosphere. Near-storm environmental features shown include a west-to-east outflow boundary (which additional storms would develop upon) and the surface warm front (designated by the red line in the image). Also note the cumulus clouds that are aligned in parallel "streets" southeast of the storm - an indication that strong southeasterly unstable inflow air was being ingested into the storm's updraft, fueling its strength.

Upper Air Analysis

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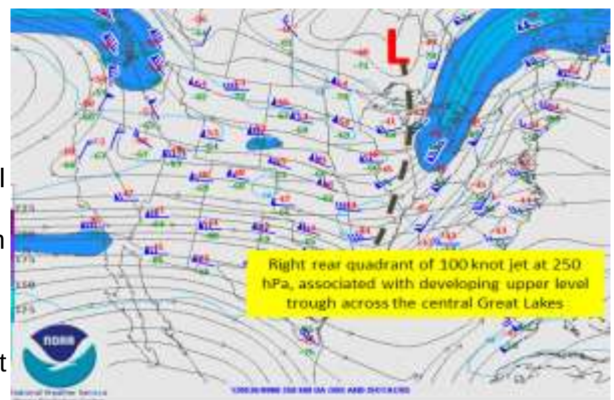

In this section we will discuss the pre-storm upper air conditions, which helped to produce severe weather across the Weather Forecast Office Burlington county warning area (CWA). A strong 100 knot anticyclonic curved 250hPa was lifting across the eastern Great Lakes into central Canada and placing our region in a very favorable region of upper level divergence, which promoted deep thunderstorm convection.

This strong jet energy was associated with a digging mid/upper level trough and cold pool aloft located over the central Great Lakes. Figure 8 shows the 250hPa (35,000 feet above the ground level) upper air analysis on 30 May 2012 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).

Sounding and Surface Data

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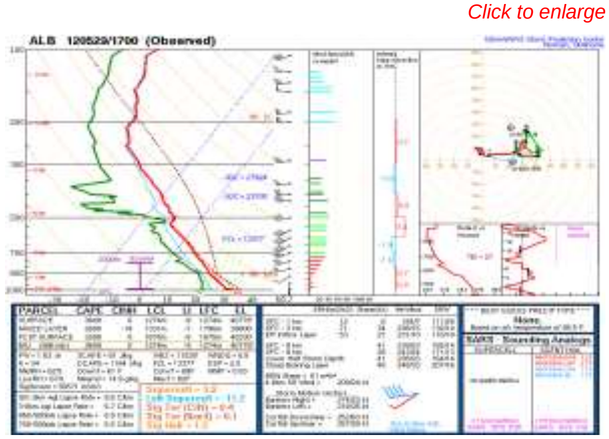

In Figure 9, the early afternoon sounding taken above Albany, NY at 1700 UTC (1 PM) shows several very important features. One of the most important is the very large amount of CAPE and the lack of any CIN. The sounding shows over 3500 J/kg of surface-based CAPE, which is more than enough for development of thunderstorms.

The characteristic of the CAPE also plays a big role in thunderstorm features. This CAPE was quite wide which allowed for explosive updraft and thunderstorm development. The CAPE also had a significant amount contributed to it within the "hail-growth zone" which is the layer of the atmosphere between -10 C and -30 C, where hail growth is optimized.

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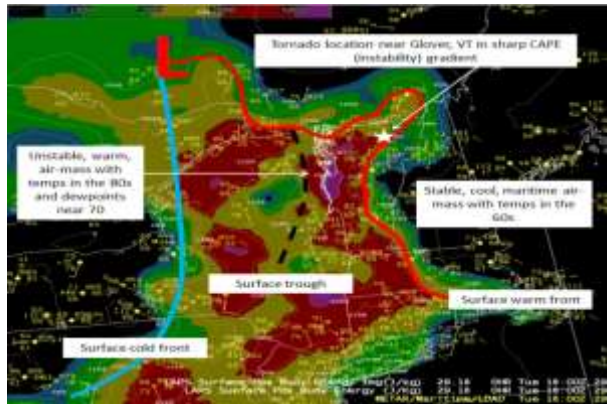

All of the features mentioned above combined with potent surface features to create a volatile day across the North Country. Figure 10 shows the surface warm front located along the Green Mountains of Vermont, separating warm and humid air from the cooler maritime air. This enhanced low level convergence (southeast winds to the east of the front, southwest winds to the west of the front) and turning of the winds in the low levels, leading to added helicity and directional wind shear. Notice that the location of the tornado was along the warm frontal boundary. This was the same warm front that was responsible for the development of heavy rain and thunderstorms the night before. Just west of the warm front was the feature that was the initial focus of thunderstorm development, a prefrontal trough. This was responsible for the first round of thunderstorms that affected the region between 1 and 4 PM. The cold front back off in Western New York was the focus for thunderstorm development across New York that later propagated eastward between 4 and 8 PM with a second round of thunderstorms.

Severe Weather Parameters

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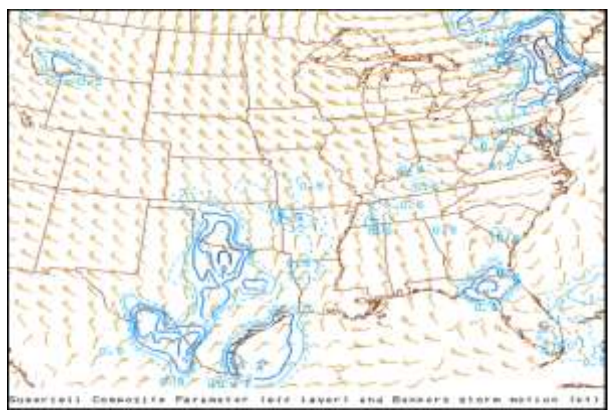

Figure 11 shows the values of the Supercell Composite Parameter (SCP). Supercell thunderstorms tend to form in unstable environments with large amounts of vertical wind shear. The SCP shows a quick representation of the "composite" effects of both instability and shear.

Areas in which values are at or greater than 1 indicate areas where supercells may be more likely, as the combination of vertical wind shear and instability in these areas are sufficiently high enough to support their formation. SCP values are greater than 1 across interior New England; however, SCP values are as high as 12 across the Champlain Valley. The environment clearly supported supercells across most of interior New England; but especially so across the Champlain Valley.

Precipitable Water

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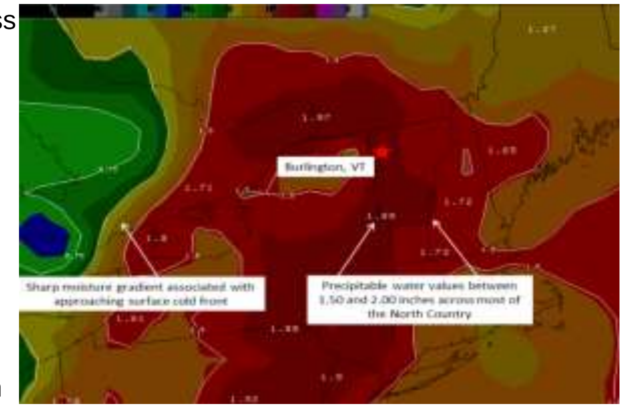

Figure 12 shows precipitable water values across the North Country during the afternoon on May 29th. Precipitable water is the depth of moisture in a column of the atmosphere. This is a strong indicator of the potential for heavy rain at any given location. A sharp moisture gradient is visible across Ontario, Canada associated with the surface cold front approaching the Saint Lawrence Valley. Air ahead of the approaching cold front in the warm sector was very saturated with precipitable water values approaching 2 inches. This is two standard deviations above normal for our region for the month of May. With precipitable water values this high it became clear to forecasters that heavy rain would be possible in any thunderstorms. This threat was recognized and a flash flood watch was issued around 11 UTC, following widespread 1 to 2 inches rainfall totals during the overnight hours and ending early Tuesday morning.

Part III: Radar Analysis

Radar Mosaic Overview

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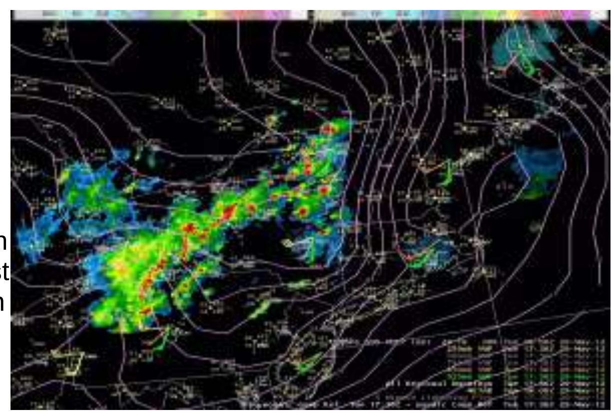

Figure 13 shows a composite radar mosaic image loop from 1736 to 2200 UTC May 29th. The strongest storms are those that show dark red and/or purple shading, corresponding to 60-70 dbZ reflectivity values. The loop shows that initial cells developed in the Champlain Valley of New York, just to the east of the Northern Adirondacks and migrated eastward into northern and central Vermont. By 1830 UTC, the strongest storms were the supercell moving across eastern Franklin, northern Lamoille and Orleans Counties, and the cluster of severe thunderstorms entering Addison County from Essex County in New York. By 1900 UTC, additional thunderstorms were developing in a line along an outflow boundary left from the northern Vermont supercell and would push into Chittenden and Lamoille Counties. From 2000-2200 UTC the main severe weather threat came from the line of thunderstorms moving from Warren County in New York across Rutland and Windsor Counties in Vermont.

Orleans Counties (EF0 Tornado near Glover, Vermont)

On 29 May 2012 a supercell thunderstorm tracked from near Altoona, NY across the northern Champlain Valley up the Missisquoi River basin, then southeast into southern Orleans County, before weakening across eastern Vermont. A supercell is a thunderstorm that is characterized by the presence of a mesocyclone; a deep, continuously-rotating updraft, which can and did produce a tornado during this event, along with very heavy rainfall. 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. This supercell produced golf ball size hail near Albany, Vermont, along with rainfall amounts of 2 to 4 inches in a very short period of time.

Click to enlarge

Figure 14 below is a digitized damage path from Google Earth of the tornado 3 miles southwest of Glover, Vermont. The total tornado path length was a third of a mile and about 100 yards wide.

The lighter blue color in the image below suggests surface winds near 70 knots based on uprooted softwood trees and minor structural damage to a house. Meanwhile, while the outline color had damage consistent to winds around 50 knots with tree limbs broken off and some smaller 6 to 8 inch diameter trees blown over.

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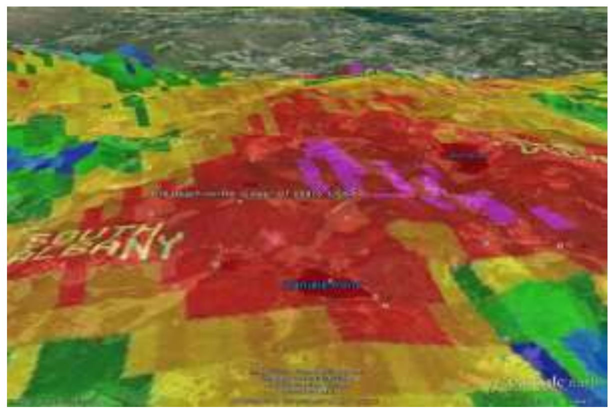

Figure 15 shows the KCXX 1.3° reflectivity at 1926 UTC on 29 May 2012, along with the location of tornadic damage 3 miles southwest of Glover, Vermont, with Google Earth as the background image. This image clearly shows a hook-like reflectivity structure, which is very typical of tornadic producing supercells.

The locations of the tornado occurred within the hook-like structure. Given the distance from the radar and location east of the Green Mountains, sampling of this storm was very poor in the lowest elevation scans. During the damage survey, the team confirmed the tornado occurred near a ridge top, with a west to east valley helping to channel low level easterly winds into the storm and enhance the tornadic circulation.

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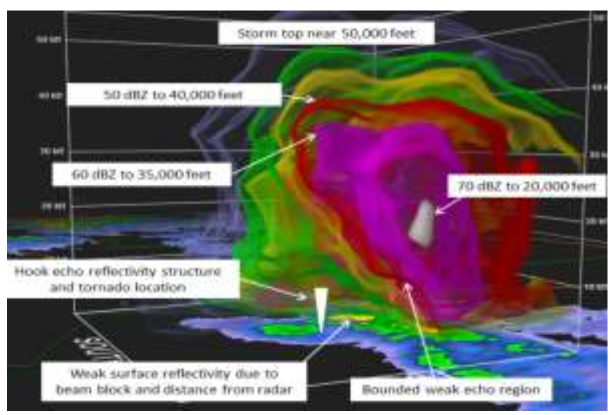

Figure 16 shows a reflectivity cross section at tornado touch down 3 southwest of Glover, Vermont at 1926 UTC on 29 May 2012. This 3-D image shows well-structured supercell thunderstorm with a 70 dBZ core to 20,000 feet and a storm top of 50,000 feet or close to 9 miles tall in the atmosphere.

The surface reflectivity gradient in the image shows a weak hook like signature, but beam blockage from the Green Mountains, resulted in poor data sampling. Also, from the image a bounded weak echo region is present, suggesting a very strong storm updraft, which helps in the development of large hail. The white triangle is the location of the tornado, in the southwest rear flank of the storm, very close to the descending rear flank downdraft and the enhanced reflectivity core.

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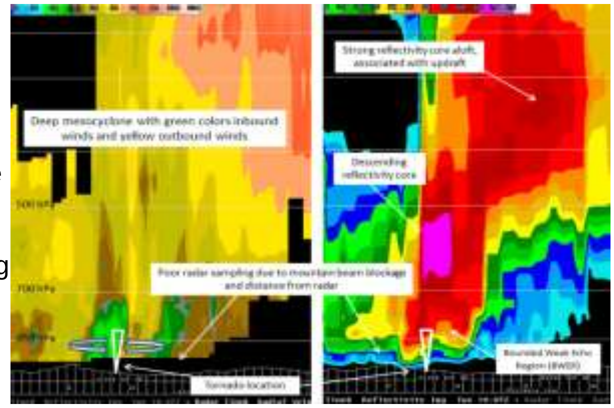

Figure 17 shows a velocity (left image) and reflectivity (right image) cross section at 1907 UTC on 29 May 2012, 23 minutes before confirmed tornado touch down. The velocity cross section clearly shows a deep mesocylone circulation thru 700 hPa. The green colors on the left image, indicate winds coming toward the radar at 20 to 30 knots, while the yellow colors show outbound winds of nearly 40 knots, creating a total storm rotation of 65 knots. You can also see how the mountains to the west of the storm, results in significant low level beam blockage in both the velocity and reflectivity data. The very strong storm updraft and well established upper level divergence pattern, helped to carry 50 dBZ reflectivity cores above 500 hPa (right image). The white triangle shows the position of the developing tornado, in the southwest flank of the storm, very close to a descending reflectivity core. The best cyclonic circulation is co-located with the descending rear flank downdraft and ascending forward flank updraft, which is very typical of well-established supercell thunderstorms.

Essex County, New York Storm near Moriah (Golf Ball Hail)

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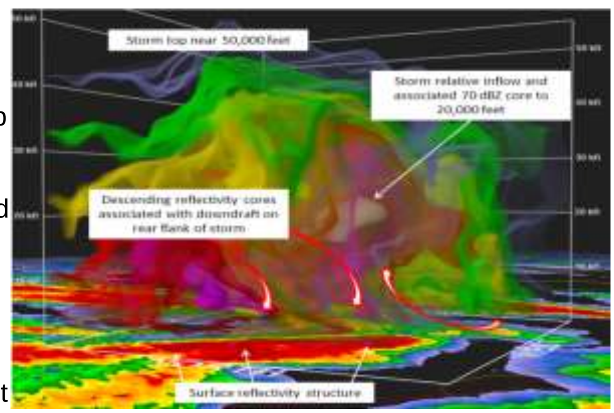

In this section we will examine the supercell thunderstorm which produced golf ball size hail near Moriah, New York. Figure 18 shows a very tall heavy precipitation supercell, with a storm top near 50,000 feet at 1817 UTC on 29 May 2012. This storm also had a 70 dBZ core to 20,000 feet, which was well above the freezing level, and provided good indication of large hail, within the storm core.

Also, from the image you can see the bow echo reflectivity structure associated with the descending reflectivity core, which would suggest the potential for gusty thunderstorm winds. From the reflectivity structure a shelf cloud signature seems likely as the storm crossed the southern Champlain Valley, given the updraft/downdraft interaction.

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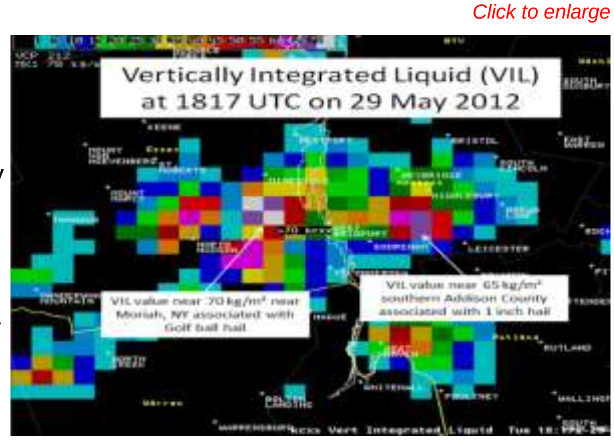

Figure 19 shows the KCXX Vertical Integrated Liquid (VIL) at 1817 UTC on 29 May 2012. VIL is an estimate of the total mass of precipitation in the clouds. The measurement is obtained by observing the reflectivity of the air as obtained by radar. This measurement is usually used in determining the size 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 19 shows VIL (pink/purple color) values between 65 and 70 kg/m2 near Moriah, NY. This indicates a very well developed updraft, which produced golf ball size hail at Moriah, NY. In addition, severe hail was observed in southern Addison County associated with VIL values between 60 and 65 kg/m2.

Rutland County, Vermont Storm near Brandon

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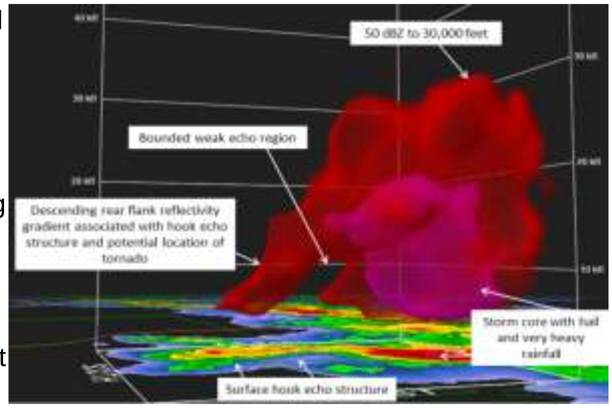

The final storm we will be discussing was located near Brandon, Vermont and was another well-established supercell with strong rotation, but never produced any damage. This supercell developed near Ticonderoga NY, then tracked east into Shoreham, VT, before weakening in western New Hampshire during the early evening hours. No thunderstorm wind damage occurred with this storm, but hail up to 1.25 inches in diameter occurred at Shoreham at 1945 UTC on 29 May 2012. Figure 20 shows the GR2 Analyst 50 dBZ or greater reflectivity near Brandon, VT at 2000 UTC. This shows the 50 dBZ core to 30,000 feet, with a large 60 dBZ or greater reflectivity core in the forward flank of the storm, associated with very heavy rainfall and large hail. The image also shows an elevated bounded weak echo region, associated with strong storm updraft, with a descending rear flank reflectivity core near the hook echo signature in the southern flank of the storm. This was collocated within an area of very strong gate-to-gate mid-level (8000 feet above ground level) rotation.

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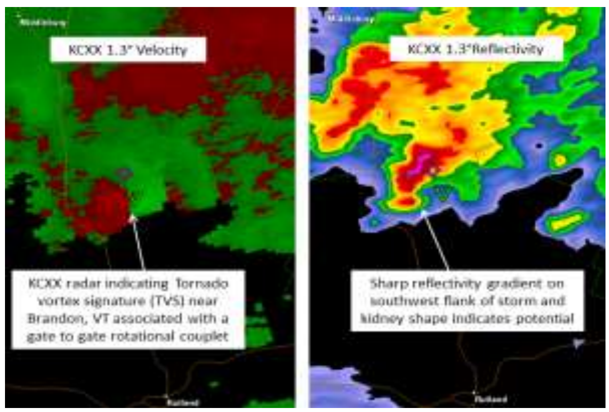

This strong cyclonic rotation can be seen in Figure 21 which shows the KCXX 1.3° velocity (right image) and reflectivity (left image) at 2000 UTC on 29 May 2012 near Brandon, VT. The green colors show inbound winds toward the radar of 30 to 40 knots, while the red colors are outbound winds of 30 to 40 knots with a total mid-level rotation of 75 knots. The lower level data had poor data sampling and deliasing problems with the velocity data. The green triangle in figure 21 shows the KCXX radar was indicating a tornado vortex signature, suggesting a strong potential for a tornado, due to the gate-to-gate rotation within the storm. Also, the pink square was suggesting very large hail was possible within this supercell, due to the very tall reflectivity core. Finally, from the reflectivity image on the right, you can clearly see a well-defined hook echo to the reflectivity structure. This also would suggest the potential for a tornado, given this storm structure, but this feature was in the mid-levels around 8000 feet along with the velocity couplet and never reached the ground. The storm report shows the NWS at BTV only received large hail for this storm.

Part IV: Hydrology

Situational awareness of antecedent rainfall conditions was a major factor in warning decision making for flash flood warnings on Tuesday afternoon. Showers and thunderstorms which moved through during the overnight hours into the morning on the 29th produced rainfall amounts ranging from one to two inches. Also, the month of May to date had been wet, with rainfall from May 1st - 28th ranging from 2.5 to over 5 inches in isolated locations. Forecasters recognized that it would not take a lot of additional rainfall to produce flood problems.

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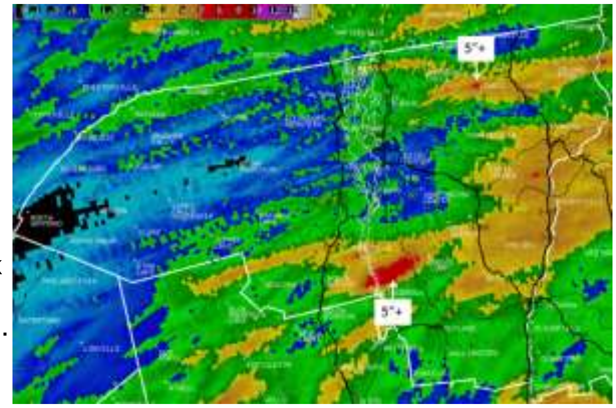

Figure 22 shows a Northeast Mosaic of storm total rainfall between 12 UTC on 29 May to 12 UTC on May 30th; this does not include the rainfall during the overnight hours on May 29th. Highlighted are two areas that had over 5 inches of rain throughout the event.

These areas included near Lowell, Vermont and another across eastern Essex County, New York into southern Addison County, Vermont. These two areas had some of the most serious flooding. The area near Lowell in northern Vermont had more devastating damage due to the mountainous terrain. These slow moving, training heavy precipitation supercell thunderstorms, created these treacherous conditions.

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Figure 23 shows one hourly rainfall rates during the height of the storms on May 29th. Rainfall rates surpassed three inches an hour in Addison County, VT. Two inch rainfall rates were observed across the northern tier of Vermont. This heavy rain flooded many roads in Addison County, causing them to become impassable.

The more serious damage in northern Vermont, near Lowell and Belvidere, washed out entire roads. Many rivers jumped their banks flooding fields and farmland, and washouts along rural dirt roads caused them to need to be rebuilt.

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Figure 24 is a hydrograph from the Missisquoi River at North Troy. Runoff from the storms across northern Vermont flowed into the Missisquoi River and then northward to the Canadian border where the North Troy River gage is located. During the morning hours the gage height rose from just below 2 feet to over 4 feet following heavy rain from thunderstorms which moved through the region overnight.

With next round of heavy rain during the afternoon, the gage height rose about another 4 feet, just cresting below flood stage Tuesday night. In twenty-four hours the gage height rose over 6.5 feet, peaking less than a foot below flood stage.

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Figure 25 is a Google map background showing two of our flash flood warning polygons issued and a plot of the associated flash flood reports across the region.

The blue raindrops represent locations where flooding was reported. These are the towns that were hit the hardest by the heavy rain which caused flash floods. Many other areas had minor flooding issues.

Part V: Conclusion/Pictures

The first major severe weather event of the season occurred due to a number of important features. A very sharp surface warm front slowly moved northeastward on the night of May 28th. Surface temperatures were in the 50's with dew points in the 40's near Montreal, Quebec north of the front, while south of the front; temperatures in central New York were in the upper 70's with dew points near 70 degrees. This was the primary focus for heavy rain and thunderstorms during the night of May 28th into the morning of May 29th. This primed the area for a flooding threat with a widespread area of greater than one inch of rain. As the warm front moved northeastward, the warm and moist air mass moved across most of the North Country with temperatures in the 80s and dew points around 70 degrees. This very unstable environment, combined with the warm front draped across central Vermont and a surface cold front and pre-frontal trough in New York, helped to produce strong to severe thunderstorms across the North Country during the afternoon hours on May 29th, which transitioned into a significant flash flood event during the late afternoon and evening hours.

This severe weather event included a confirmed EF0 tornado near West Glover, Vermont, along with numerous reports of large hail and damaging thunderstorm winds. The thunderstorms were also accompanied by very heavy rainfall amounts of 2 to 4 inches with localized radar estimates near 6 inches which caused significant flash flooding. As a result, many roads were washed out and numerous rivers and streams had sharp rises.

The most severe weather and flooding reports were concentrated from the eastern Adirondack Mountains in northern New York into central and northern Vermont. These reports were associated with several long-tracked heavy precipitation supercells, which continued into parts of New Hampshire. Pictures of the flooding, hail, and tornado damage can be seen below in figures 26 through 32.


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