The Four Seasons

National Weather Service Burlington, VT

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Letter from the Editors

Welcome to the Spring Edition of The Four Seasons, a quarterly newsletter issued by the National Weather Service in Burlington, VT. In this edition we'll take a look back at two notable snow storm events during this past winter. We'll also look at where model forecasts are headed using the National Blend of Models, and how we use satellites to look at ice cover on Lake Champlain. Finally, we will look towards our next season, Summer, with a detailed look at different types of thunderstorms, as well as delve into one of the unique sections of our website, accessing Lake Champlain point forecasts. Thanks for reading and we hope you enjoy the newsletter.

19-21 January 2019 Winter Storm

-Brooke Taber and Peter Banacos

A major winter storm blanketed Vermont and northern New York with 10-20" of snow on 19-21 January 2019, with isolated totals near 21" across the eastern slopes of the Adirondacks in Essex County, New York. Figure 1 (next page) shows the storm total snow for the storm. The bulk of the snow fell on Sunday, January 20. Aside from a brief mix of sleet and freezing rain across the southern half of Vermont (8am until noon EST on 20 January), precipitation fell as all snow across the region. The event crossed 3 calendar days at the Burlington International Airport (BTV), totaling 18.6" of snow, the 18th greatest storm on record, and 5th largest in January. Of that, 15.6" of snow fell on Sunday, January 20, setting a new record for the date. Snowfall rates peaked at 2.4"/hr during the mid-morning hours on January 20.

The main impacts of the storm were travel related. Even at that, travel impacts were mitigated by the majority of the snowfall occurring over the weekend, when overall traffic volume tends to be light. Snow ratios early in the storm were near 10:1, despite arctic air in place with below zero (Fahrenheit) surface temperatures. In fact, this was the "coldest" significant snowstorm in recent memory, with temperatures in the northern Champlain Valley below zero throughout much of the snowfall, and wind chill values near 20 below F. Despite the small snow-to-liquid ratios, the dry nature of the snow was not conducive to snow clinging on trees and powerlines. Thus, power outages were not a significant issue for this event.

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SYNOPTIC SETUP

The large-scale synoptic setup featured a 1034 millibar (mb) arctic high pressure anchored over eastern Canada, with temperatures -20^{o}F to -30^{o}F advecting toward northern New England on brisk north winds of 10 to 20 mph. Meanwhile, a 998 hPa low pressure was developing over the Ohio River Valley with very warm moist air moving north toward the Mid Atlantic states on the evening of 20 January 2019. Temperatures across the North Country ranged from the -5^{o}F across the Saint Lawrence and northern Champlain Valleys to +10^{o}F near Springfield, Vermont in the Connecticut River Valley. Figure 2 shows the 00 UTC surface analysis on 20 January 2019.

During the pre-dawn hours on January 20, bands of light to moderate snow were lifting from south to north across most of central and northern New England, including the entire North Country, with surface visibilities below 1 mile. The 12 UTC surface analysis placed 991 hPa low pressure northwest of Philadelphia, PA with a sharp coastal front extending into extreme southern New England. Meanwhile, the air mass was still extremely cold across the Saint Lawrence Valley into northern Vermont with temperatures only in the single digits, while readings warm into the mid teens across portions of Rutland and Windsor counties. This extremely sharp thermal gradient, helped to enhance areas of moderate snowfall across the eastern Adirondacks into most of Vermont during the daytime hours on January 20.

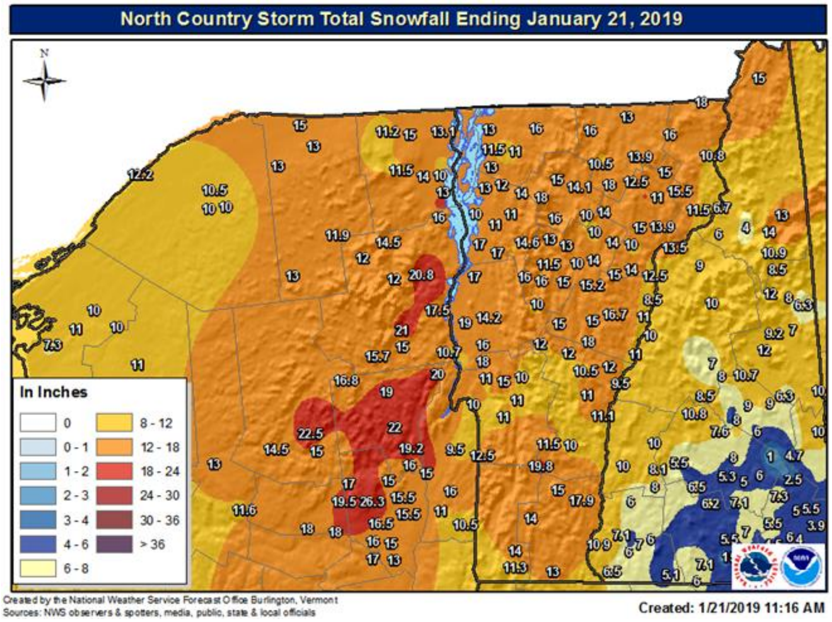

Fig. 1 (above). Storm total snowfall amounts 19-21 January 2019.

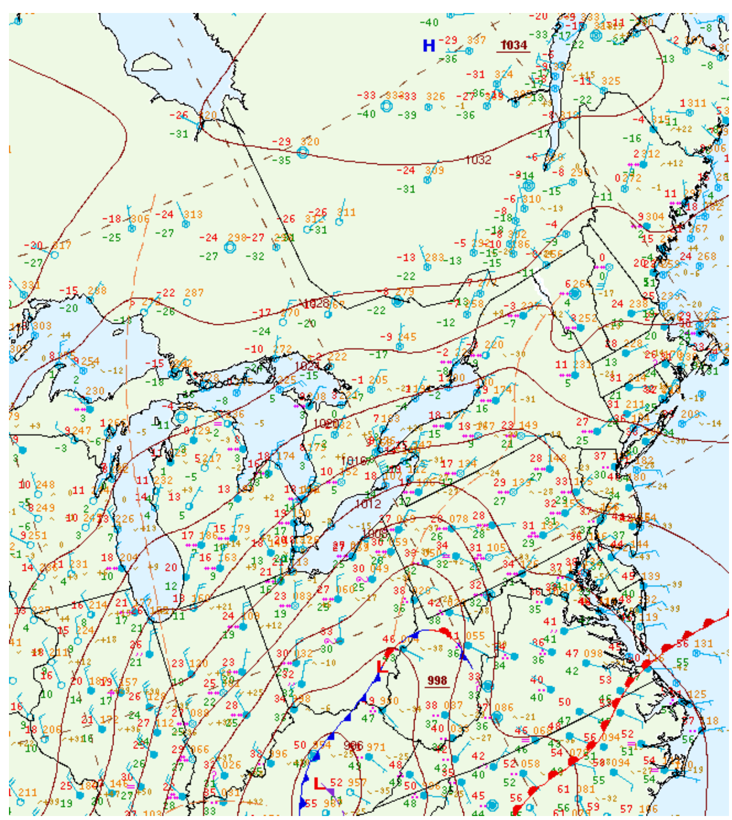

Fig. 2. Surface analysis 00 UTC on 20 January 2019.

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Figure 3 is the 1200 UTC 20 January 2019 upper air sounding from Albany, New York, which was representative of the air mass advecting into northern New York and Vermont during this winter storm. Initially, the very cold air mass in place created snow ratios around 10:1, as the favorable dendritic growth zone was near the surface. However, favorable microphysical conditions developed as warming occurred between 850-700 hPa layer associated with southwest jet of 30 to 40 knots. This enhanced deep layer moisture, while expanding the favorable dendrite growth zone (-12C to -18C), resulting in enhanced snowfall rates and overall better "fluff factor". Snow-to-liquid ratios early in the storm were around 10:1, and increased to 15-20:1 toward the later part of the storm. The warm nose around 800 hPa did push temperatures above 0C aloft, which caused some sleet to mix with the snow across southern Vermont on the morning of January 20th.

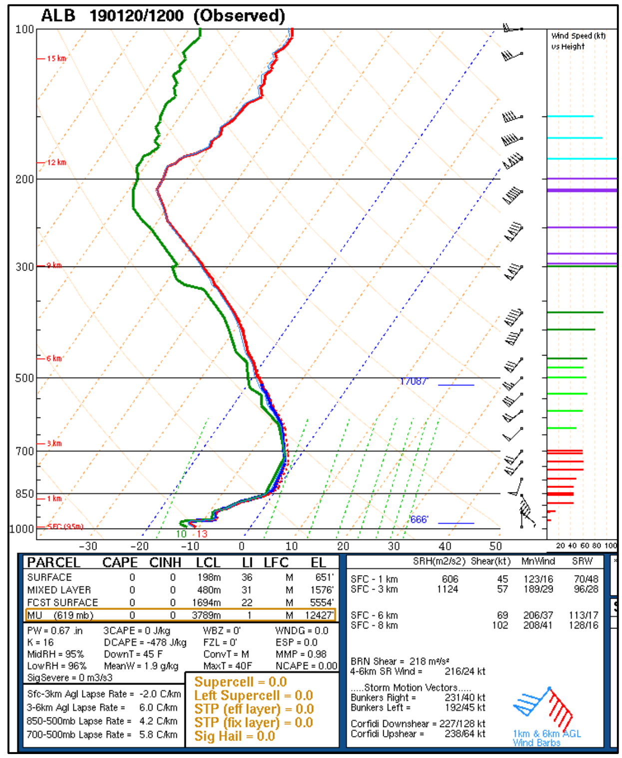

Fig. 3. The 12 UTC 20 January 2019 sounding and associated analysis from Albany, NY.

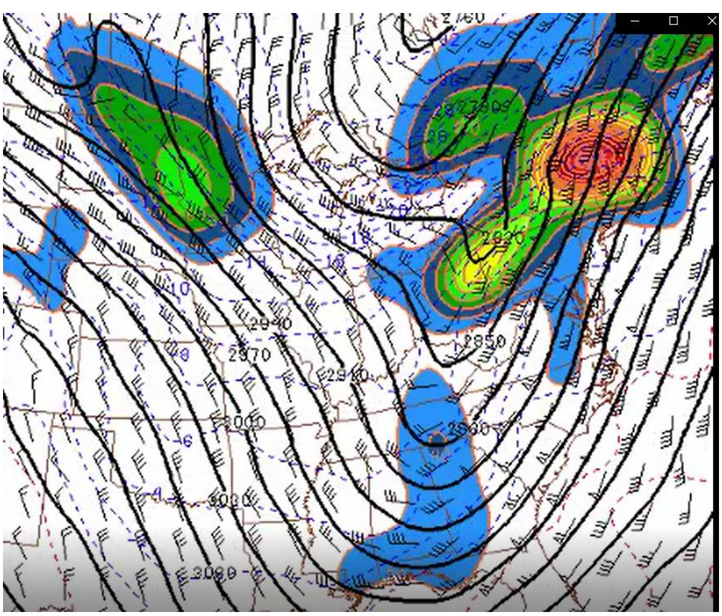

Fig. 4. The 700 hPa Petterssen Frontogenesis (color filled), 700 hPa heights (black lines), temperatures (blue dotted lines), and winds (black barbs) on 20 January 2019.

MESOSCALE CONDITIONS

Several favorable mesoscale ingredients contributed to the moderate to locally heavy snow event on 20 January 2019. These features included strong low-to-mid level frontogenetic forcing, deep and rich moisture advection, and favorable thermodynamics profiles, including a saturated dendritic snow growth layer (-12C to -18C). This long duration winter storm featured multiple bands of moderate to heavy snowfall lifting from south to north across our forecast area associated with frontogenetic forcing at different levels of the atmosphere. The initial burst of moderate snowfall was associated with strong 700 hPa frontogenetic forcing, as southerly winds at 10,000 feet of 50 to 70 knots were advecting warm, moist air into a very cold low-level air mass. The broad isentropic ascent, or "overrunning",

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enhanced the synoptic scale forcing to produce a widespread 2 to 6 inch snowfall early on January 20th. Snowfall rates were generally 0.5 to 1.0 inch with snow-to-liquid ratios in the 10 to 1 range during this initial 700 hPa frontogenetic forcing, and surface visibilities around 1 mile. Figure 4 (previous page) shows a loop of the 700 hPa Petterssen Frontogenesis forcing, from the RAP-based NCEP/SPC Mesoanalysis from 0100 to 0800 UTC on 20 January 2019.

CONCLUDING SUMMARY

The 19-21 January 2019 snowstorm will be remembered for producing 10-20 inch snowfall amounts during a period of arctic temperatures. The storm sets a benchmark for below 0°F surface temperatures during much of the event, in association with arctic high pressure anchored across Quebec. Combined with very low wind chill values down to 20 below, such a situation was potentially dangerous in the event any travelers became stranded in their vehicles. The accumulating snow occurred mostly during a Saturday night/Sunday morning, and fortunately, overall known travel impacts during the storm were limited. A positive impact from this major snowstorm was the significant boost to winter sports enthusiasts and the businesses that benefit from winter activities. The storm occurred during a major “ski weekend” associated with the Martin Luther King Jr. holiday, and resulted in deep powder for alpine skiers on Sunday (1/20) and Monday (1/21). The final two figures below show pictures during and after this major winter storm at the Burlington International Airport.

Fig. 5 (above). Photo taken on roof of Burlington International Airport looking east across the runaway toward Vermont Air National Guard around 1100 UTC on 20 January 2019.

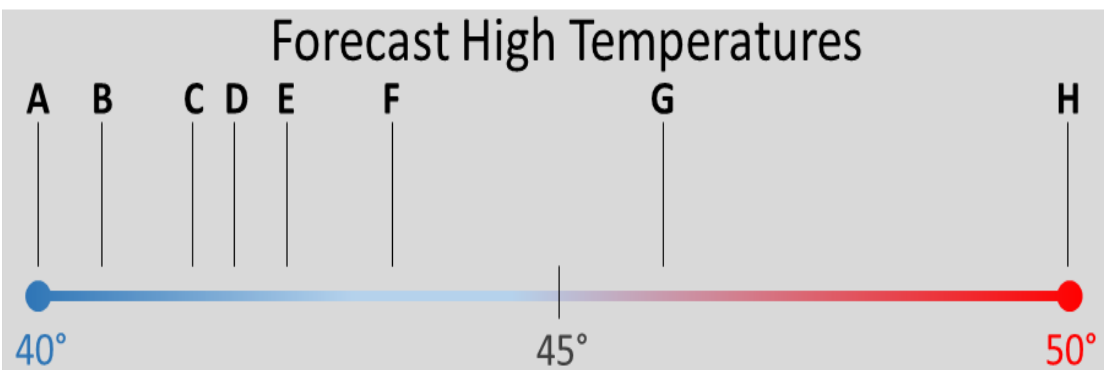
Fig. 6. Photo taken at Burlington International Airport on 21 January 2019, showing the deep snowfall which occurred with the major winter storm.

The Latest in Forecasting: National Blend of Models

-Robert Haynes

Whether or not you are an avid reader of our Area Forecast Discussions, or an attentive listener to weather reports on our local news, names of weather forecast models are bound to come up, especially in high impact weather. “The American GFS model has heavy snow…” or “The European model is faster and drier…” might be examples of how forecast models get interpreted. Due to the complex nature of solving atmospheric equations, differences between weather models expand over time, and can lead to one weather model calling for a pleasant, partly cloudy spring day, while another weather model might produce light snow that same day.

Meteorologists are tasked with analyzing and deciding how to best approach these differences and communicate them. The approach we will discuss here is incorporating various weather models to develop better weather forecasts. In an Area Forecast Discussion or independently produced weather forecast, you might note references to a “model consensus” or “blended data”. If you were forecasting the high temperature based on these weather models with forecasts between 40° and 50° F, what would you forecast?



Without any knowledge of the weather pattern, a forecast high between weather model B and weather model F would be a good starting point because model consensus favors a high temperature between 40° and 45°. If we just had the one outlier, weather model H, our forecasts would likely be too warm. Forecast skill is improved when several models are available to blend, and it lends us greater confidence in the forecast, which enhances communication. Expansion of this concept has taken place over the last several decades with greater computing power available to us now. One of the latest products of this developing science is the **National Blend of Models (NBM).**

After the Eastern US incurred widespread damage from Hurricane Sandy, Congress passed the 2013 Disaster Appropriations Act, also known as the Sandy Supplemental. Within the funding, provisions were made to develop the NBM. The goal of the NBM is to enhance decision support in building a Weather Ready Nation. Each National Weather Service already generates their own set of blended forecasts. The purpose of the NBM is to produce these blended forecasts and data processing on a national scale. The goal is to skillfully produce quicker forecasts amongst National Weather Service offices and provide a baseline that any office can confidently use (Figure 1, next page).

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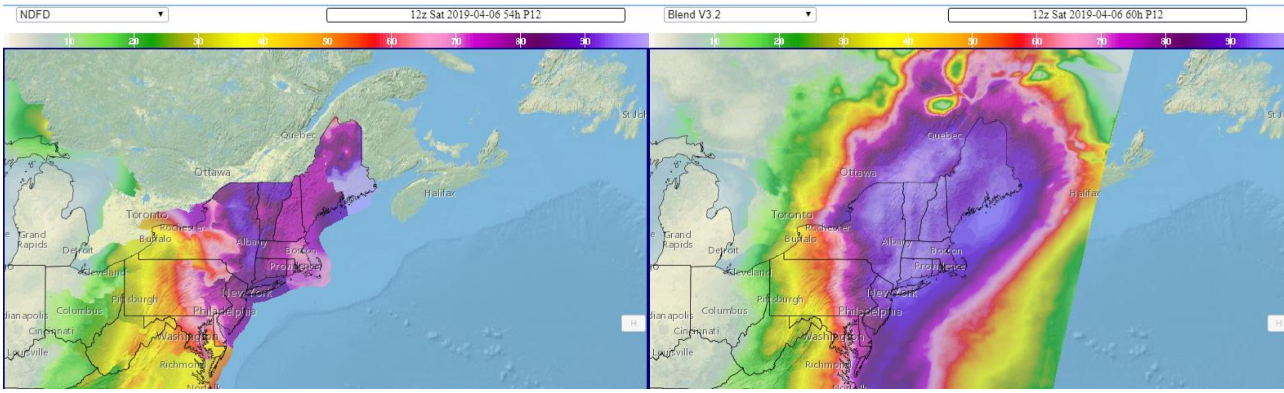

Figure 1: Forecast grids from various NWS offices found on the National Digital Forecast Database (left) and the National Blend Version 3.2 (right) for 12Z Saturday April 6th.

So how will this single, national scale blending of data affect our region? The complex terrain of the North Country is challenging for forecast models. Model depictions of terrain vary in resolution and accuracy. Weather models also use different techniques to ingest data. To establish a common basis for bias-correcting weather models, the Unrestricted Mesoscale Analysis (URMA) is used. URMA contains a wide network of Automated Surface Observing Station (ASOS) and Mesonet sites. Similar to how Model Output Statistics (MOS) adjusts models with local climatology based on observations and verification for different types of terrain for each season, URMA compares model data to its analysis while grouping regions with similar terrain for adjustments in the NBM every couple months. The MOS adjusted model data is also incorporated into the NBM. Figure 2 depicts a schematic of data processing through the National Blend, which is adapted from the schematic in the Introduction to the NWS National Blend of Models Module on COMET/MetEd. The consensus of these models form the basis for the forecasts of the NBM scaled for the terrain of different regions and applied to a national database of observations.

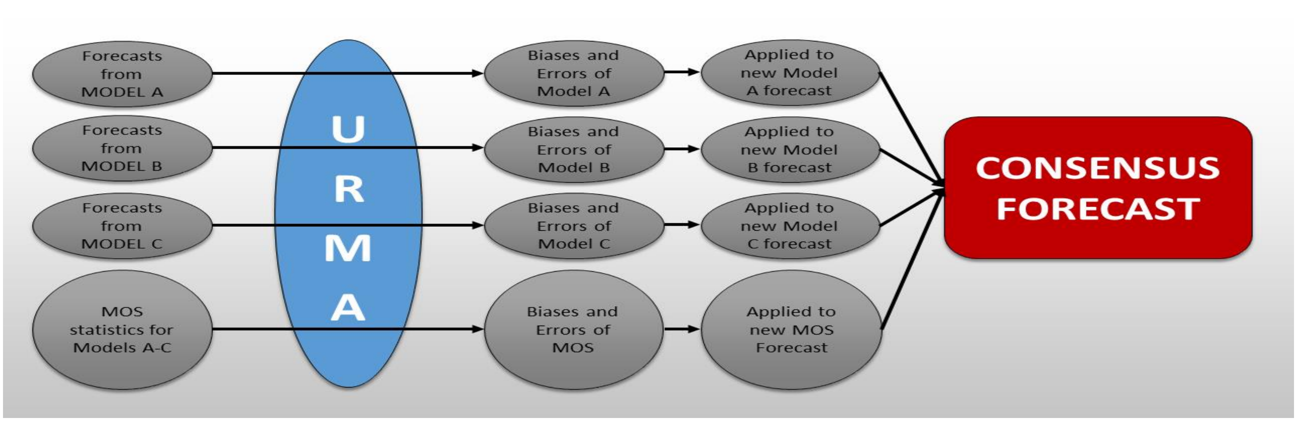

Figure 2: Collections of previous forecasts are trained through URMA, which collects an assortment of biases and errors that are applied to new forecast guidance to develop the National Blend Forecast.

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The first version of the NBM was released in January 2016, originally containing two global models and the North American Ensemble Forecast System (NAEFS). This first version only produced forecasts for the temperatures, winds, and sky cover. Over the last several years, the size and scope of the NBM has expanded. Figure 3 synthesizes these expansions in a timeline. The addition of more global models, ensemble forecast systems, and high-resolution, mesoscale forecast models has allowed for both probabilistic forecasts and hourly forecasts to be included. Aviation, marine, and fire weather forecasts capabilities have been added to encompass as many of the different fields of forecasts and data provided by the National Weather Service as possible. Current experimental runs are introducing probability of precipitation types, whether it be rain, snow, sleet, or freezing rain. Future objectives center around impact statements and forecast confidence to coincide with the headlines each National Weather Service office produces for watches, warnings, and other hazardous weather.

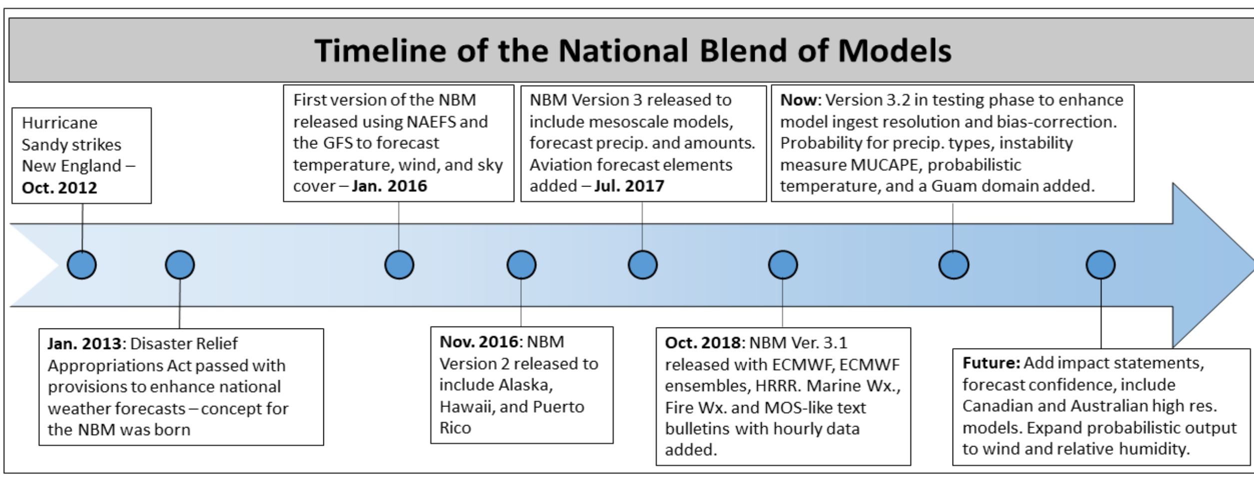

Figure 3: Timeline of the National Blend of Models since its inception, through its major iterations, and into the future.

The NBM will continue to evolve over the next several years. It includes an impressive array of forecast models and forecast elements that are continuing to expand with each iteration. Many National Weather Service offices are already using the NBM across their forecast packages as the resource has become more robust, including here at BTV. The National Blend project will help us provide more meaningful, consistent messaging to assist with coordination between our neighboring National Weather Service offices and our partners, including you. Interested in following the development of the NBM? You can find more publicly available resources regarding the National Blend at the Meteorological Development Laboratory

The 22-23 March 2019 Heavy Wet Snowfall across the North Country

-Rebecca Duell

This post storm analysis will cover the March 22 to 23, 2019 heavy wet snow storm, which caused power outages and tree damage across the North Country. There were several aspects of the storm that were especially noteworthy. The first of which is a band of heavy snow that formed over central and northeastern Vermont during the daytime on Friday March 22, resulting in localized snowfall rates up to 3" per hour. The second aspect of the storm is the northwesterly upslope snow that brought over a foot of snow to portions of the western Green Mountains and northwestern Adirondacks.

On the morning of the 22 March 2019 snow began over Vermont shortly before sunrise, quickly organizing into a band of heavy snowfall over portions of northeastern and central Vermont (phase 1 of the storm). By noon, spotter reports in eastern Addison County, Washington County, northern Orange County, and Caledonia County indicated snowfall rates between 1 and 3 inches per hour, which continued through 3 PM. Numerous spotters commented on the large size of the flakes, and the heavy, wet, and sticky nature of the snow, which made travel and snow removal difficult. By 5 PM on the 22nd, reports indicated the band had weakened, snowflakes had decreased in size, and the snow intensities had become light. At this point, the low pressure system tracked northeastward to the Maine Coast, which marked the transition to "phase 2" of the storm – the northwesterly upslope phase. It was at this point that the heaviest snow accumulations shifted to the western slopes of the Green Mountains in Vermont and the northwestern slopes of the Adirondack mountains in New York. The highest snowfall rates on the night of the 22nd were observed over the western slopes of the Green Mountains, where snowfall rates of generally 0.5 to 1 inch per hour were reported through the night. As the low pulled further away to the northeast on the morning of the 23rd, snowfall tapered off and ended by the afternoon.

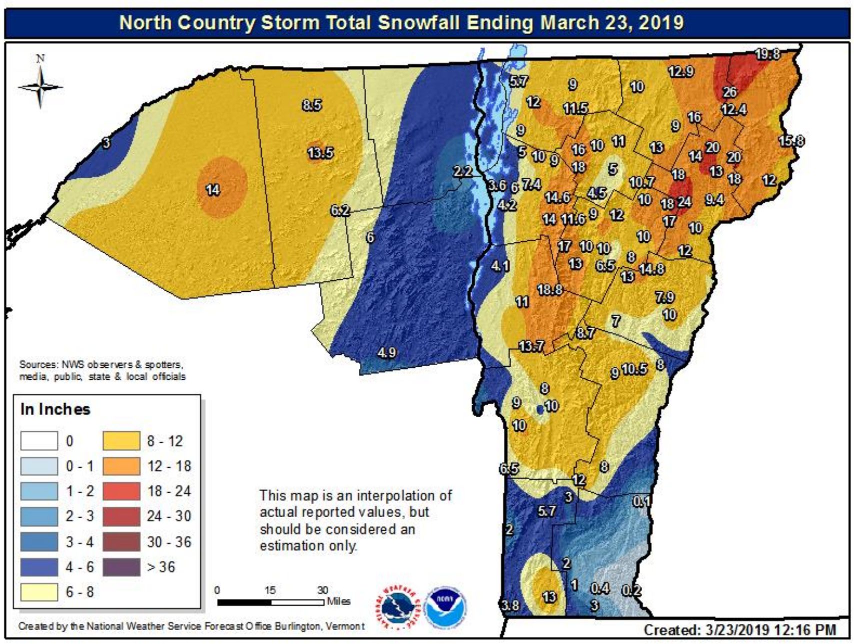

Figure 1. Storm total snowfall across Vermont and northern New York from 22nd – 23rd March 2019.

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Synoptic Setting

1. 300 hPa Analysis

A look at the 300 hPa analysis (Fig. 2) shows a dual jet structure that played a critical role in establishing strong upper level divergence over New England. Vermont sits in the right rear quadrant of a 100-125 knot jet over eastern Canada and the left front quadrant of a 125 to 150 knot jet over the western Atlantic, putting our forecast area in a region of maximized upper-level divergence (leading to surface convergence). In addition to providing divergence aloft, the upper jets were coupled to the lower atmospheric circulations, playing a key role in the cyclogenesis of the coastal low. The resultant vertical ageostrophic circulations induced by the upper jets supported strong southerly low and mid-level flow off the coast of the Mid-Atlantic and Northeastern United States, which further enhanced a zone of baroclinicity over the East Coast and set the stage for the rapid strengthening of a coastal low in the lower to mid-levels.

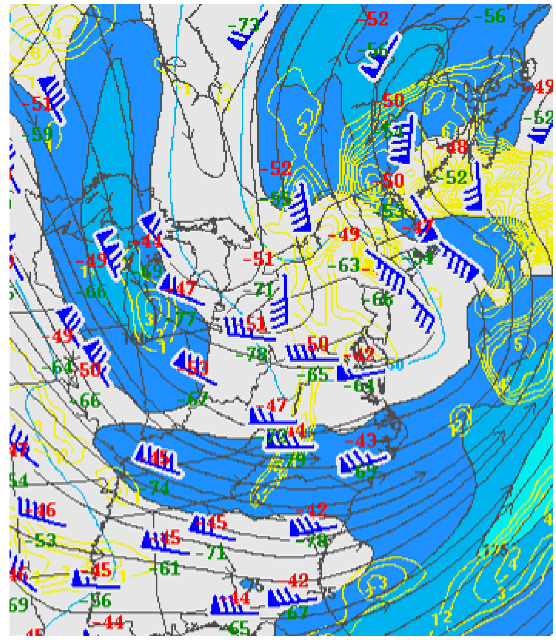

Figure 2. The 1200 UTC 22 March 2019 300 hPa analysis, showing isotachs contoured and blue shaded >=75 kts, and divergence contoured in yellow.

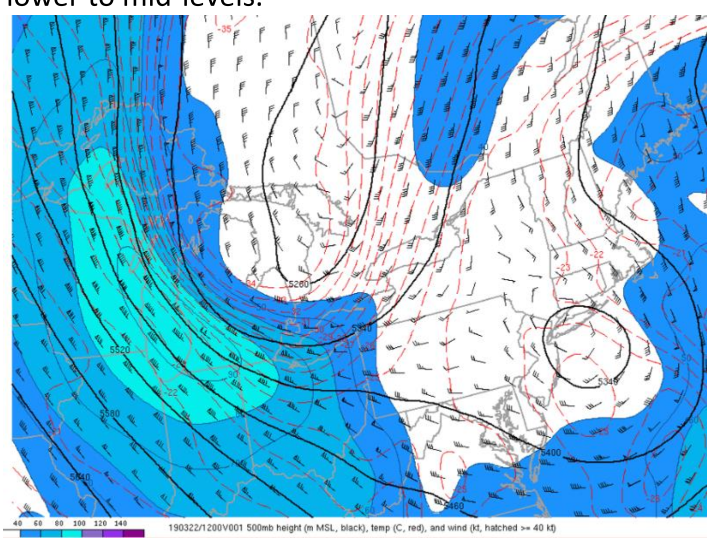

Figure 3. 1200 UTC 22 March 2019 500 hPa heights (m MSL, black) temperatures (C, red), and wind (kt, shaded >=40 kt). From the RAP-based NCEP/SPC Mesoanalysis.

2. 500 hPa Analysis

The 500 hPa analysis (Figure 3) reveals two key features of note; a sharp trough with embedded shortwave energy (not shown) diving southward over the eastern Great Lakes Region. Meanwhile, a southern stream shortwave tracked north from the Carolinas and became a closed upper low near New York City, as the two pieces of energy phased together. The 500 hPa height falls were maximized over New York and much of New England ahead of these two features.

3. 700 hPa Analysis

With the coastal low closed off at 700 hPa over New England by 00Z (0800 PM local) on the 22nd (Fig. 4a), the stage was set for easterly/southeasterly moisture advection into New England through the night. By 12Z (0800 AM local) on the 22nd (Fig. 4b), the closed low had moved to near New York City, allowing for continued mid-level moisture advection through the morning hours. By 00Z on the 23rd (Fig. 4c), the closed 700 hPa low was now located over the Maine Coast, which marked the transition to the second phase of the storm, characterized by northwesterly upslope flow. The location of the mid-level

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closed low Friday evening pulled in continental polar air from western Quebec over most of northern New York, but kept relatively warmer and moist maritime air over Vermont through the first portion of the night. This contributed to the prolonged low snow ratios Friday evening into the first part of Saturday morning, which resulted in power outages throughout the night in Vermont. The very favorable track of the deepening 700 hPa track placed the North Country in a region of maximum moisture and thermal advection, resulting in significant snowfall.

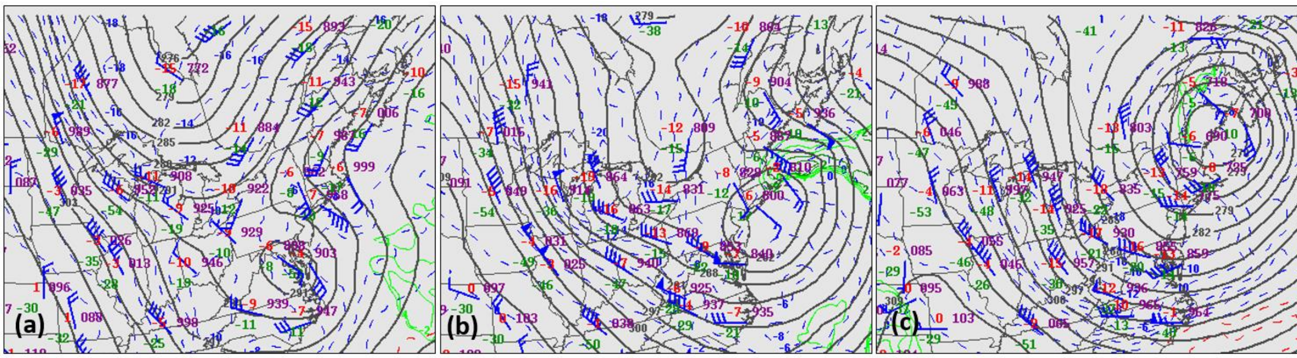

Figure 4a-c. 700 hPa upper air observations, heights (black), and temps (blue dashed line), and dewpoints (Td>=-4 contoured in light green) for (a) 0000Z 22 March 2019, (b) 1200Z 22 March 2019, and (c) 0000Z 23 March 2019.

4. Thermodynamic Profiles

Numerous spotters and members of the public relayed to the National Weather Service that the snowfall within the band over central and northeastern Vermont was "wet", and "sticky". Investigating the forecast sounding confirmed a favorable thermodynamic profile for very wet, high density snow. Figure 5 is a forecast sounding from Saint Johnsbury, in Caledonia County Vermont, valid at 1500 UTC (11 AM local time), which shows deep saturation within and below the DGZ. Given the deep saturation and relatively deep 0 to -5°C layer (extending from the surface through 700 mb) the sounding does indeed confirm favorable environment for wet and sticky snow.

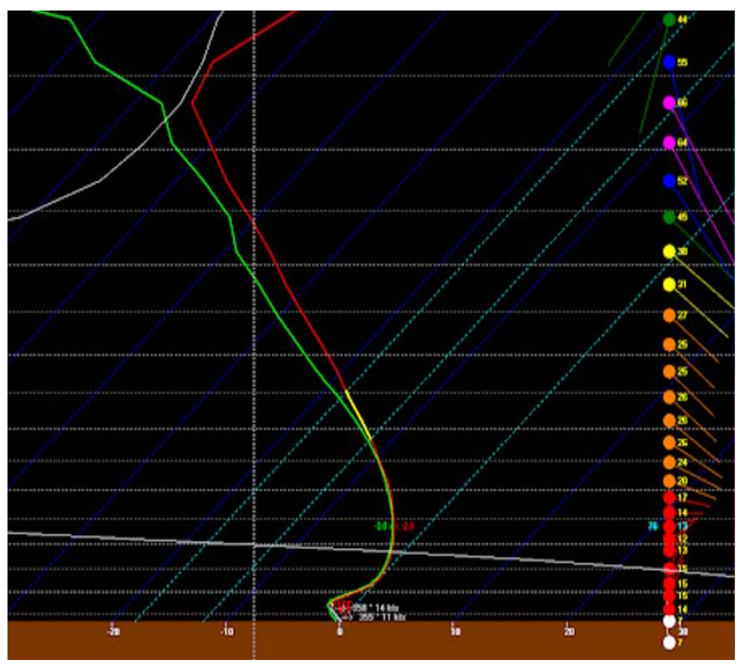

Figure 5. GFS20: Forecast sounding for Saint Johnsbury, VT, valid 1500 UTC (11 AM Local) 22 March 2019

5. Conclusion:

Several factors came together to support significant snowfall over portions of the North Country on 22-23 March, 2019. For an in-depth look at the event, including several mesoscale factors that attributed to the banded snow, challenges pertaining to snow ratios during the event, and some of the impacts, you can read the full write up here.

Radar Based Examples of Severe Thunderstorms

-Pete Banacos

When viewed from a radar or satellite perspective, there are baseline characteristics that allow meteorologists to categorize thunderstorms into four basic types:

Type of Storm	Description
Single or Ordinary Cell	Single cells that remain isolated from other convection. These storms tend to be short-lived and disorganized.
Multicell	Storms loosely organized in clusters, containing several or many embedded cells, with new cell growth occurring along thunderstorm outflow boundaries.
Linear	Long-lived storms organized in well-defined lines or arcs of varying length.
Supercell	A rotating thunderstorm that is well-organized and long lived.

Since thunderstorms are convective features, meteorologists will often refer to these types as the "convective mode". An understanding and accurate prediction of convective mode is important to severe weather forecasting, as it helps determine the most likely type(s) of hazards, including hail, damaging winds, tornadoes, and flash flooding. A convective mode forecast is often challenging, dependent upon numerous processes and motions occurring across a wide range of atmospheric scales. The convective mode can also be influenced by the storms themselves; as storms evolve and mature they influence their surrounding environment through rain-cooled outflow and compensating motions surrounding individual storms.

Processes relevant to determining convective mode include the degree of instability, the amount of convective inhibition , the low-level and deep-layer vertical shear, the presence of any thermal or wind shift boundaries (e.g., a front, outflow boundary, or seabreeze), and the geometry of the mesoscale and large-scale forcing creating the necessary lift for thunderstorm development.

A summary of each thunderstorm type follows. The summary includes favorable environmental conditions and a description of significant weather associated with each type.

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SINGLE CELL: Single (or "ordinary") cell thunderstorms typically develop in unstable environments during peak daytime heating. However, the environment also exhibits weak vertical shear and the absence of an organizing boundary or significant large-scale weather features. As such, single cell storms "pulse" up and down quickly, as the weight of suspended precipitation will collapse downward onto the main updraft of the storm. The entire thunderstorm life cycle typically occurs in well under an hour. Severe weather is generally not favored with single cell storms, but brief downbursts as single cell storms collapse can sometimes produce localized winds reaching severe limits along with small hail (Fig. 1).

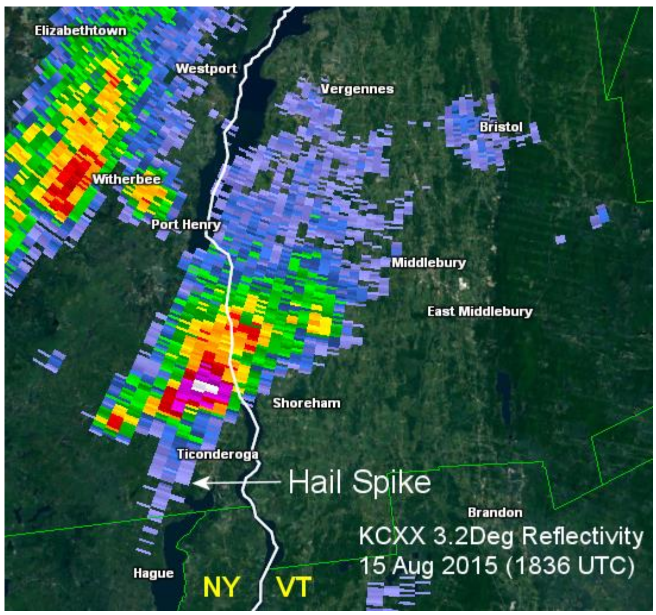

Fig 1. A briefly intense single cell thunderstorm near Ticonderoga, New York on 15 August 2015. Radar reflectivity from the Burlington, VT (KCXX) showed evidence of a three-body scatter spike (indicative of hail aloft) during its evolution.

MULTICELL: Multicellular storms develop in environments with varying degrees of instability and moderate vertical shear. Modest large-scale forcing - in the form of a shortwave trough - is typically present, but often in the absence of a well-defined surface boundary. As thunderstorms develop and evolve in relatively close proximity, storm interactions result in cell mergers and the development of new cells along outflow boundaries (Fig. 2). Because of this new cell development, multicellular storms outlast their single cell counterparts. When low-level lapse rates are steep and mid-level temperatures are cold, multicellular storms can produce scattered wind damage via wet or dry microbursts, in addition to severe hail. Sometimes multicellular storms develop upscale into relatively large mesoscale convective systems (MCSs), especially when supported by moisture and temperature advection and a low-level jet. Multicells may ultimately take on a more linear type over the course of several hours.

LINEAR: Thunderstorms can develop in a linear fashion when the geometry of the lifting mechanism is along a line or arc. This occurs near cold fronts or large-scale outflow boundaries from large rain-cooled areas from ongoing thunderstorms. Linear storms typically have

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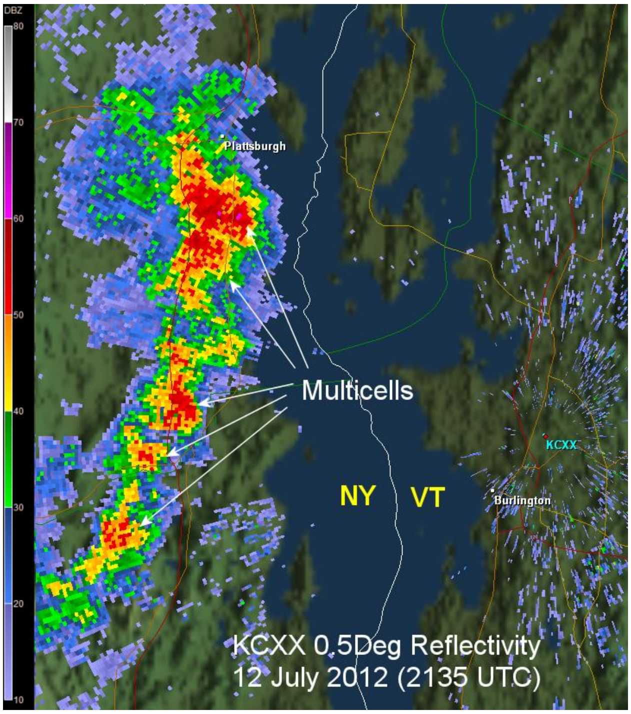

Fig. 2. A multicellular cluster of thunderstorms approaches Plattsburgh, NY on 12 July 2012, as viewed from the Burlington, VT (KCXX) radar. These storms were associated with localized damaging winds in Plattsburgh.

moderate to strong deep-layer shear. A cold front is more likely to be associated with storms oriented in a linear fashion when the vertical shear is oriented along the axis of the cold front, which allows thunderstorms to interact and merge quickly along the organizing boundary.

Linear storms are examples of MCSs, and can develop as a solid line (called a "squall line"), while others will evolve as a broken line. The main threat from linear MCSs is damaging wind and/or flash flooding. Hail is less common. Any tornadoes are generally brief because of fast-moving, rain-cooled outflow. Small or large-scale bowing segments within a line of thunderstorms can be associated with swaths of damaging winds, in what is called a "line echo wave pattern" when viewed with radar. In their most extreme form, the "derecho" is a linear MCS that produces damaging winds over large-areas over many hours as storms propagate rapidly downwind in unstable environments. Derechos are rare across the North Country, but have been documented (Fig. 3). In other cases where the line orients parallel to the deep-layer shear, storms can "train" or stagnate over an area producing prolonged heavy rain and potential flash flooding.

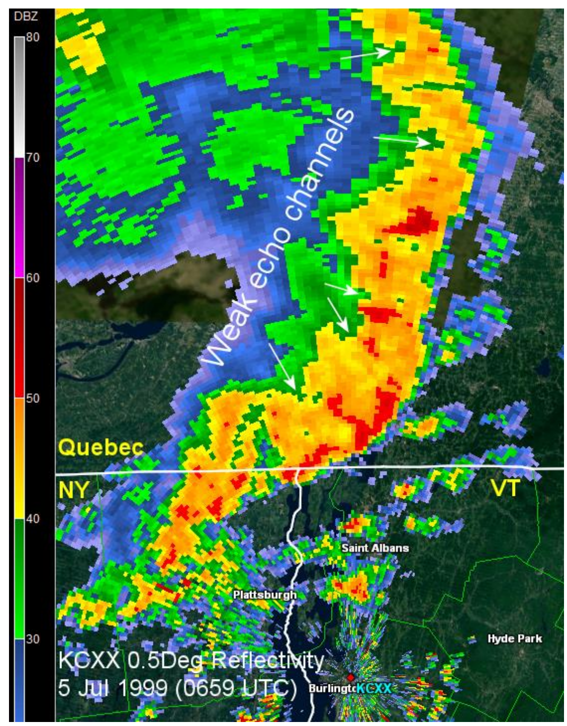

Fig 3. A forward-propagating line of thunderstorms known as a "derecho" races eastward along the international border between Vermont and Quebec during the overnight hours on 4-5 July 1999, as viewed from the Burlington, VT radar (KCXX). So-called "weak echo channels" on the upwind side of the convective line are indicative of swaths of damaging winds.

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SUPERCELL: Supercell thunderstorms are the most prolific producers of severe weather. In some slow-moving events, supercells can also result in flash flooding. Supercells are defined by a long-lived, rotating updraft (Fig. 4), allowing these large thunderstorms to persist over 1-6 hours. Supercells make use of strong deep-layer and low-level shear in order develop and persist. The magnitude of the low-level shear and turning of the winds with height modulates the threat of tornadoes with supercell storms, but most strong and violent tornadoes are associated with this type. Supercells will typically form in association with mesoscale and large-scale forcing, but removed from strong linear forcing such as cold fronts. They also form in environments with modest convective inhibition, allowing them to remain discrete as neighboring storms tend to be less numerous in such environments. If there is a dryline or cold front present, supercells are more likely when the vertical shear is oriented perpendicular to the axis of the boundary, such that individual storms do not merge quickly. The interaction of supercells with subtle boundaries - such as that resulting from thunderstorm outflow from prior convection - can play a role in enhancing the tornado threat. Owing to their long-lived rotating updrafts, giant hail (>2" diameter) is possible in supercells owing to long residence/growth times for hailstones.

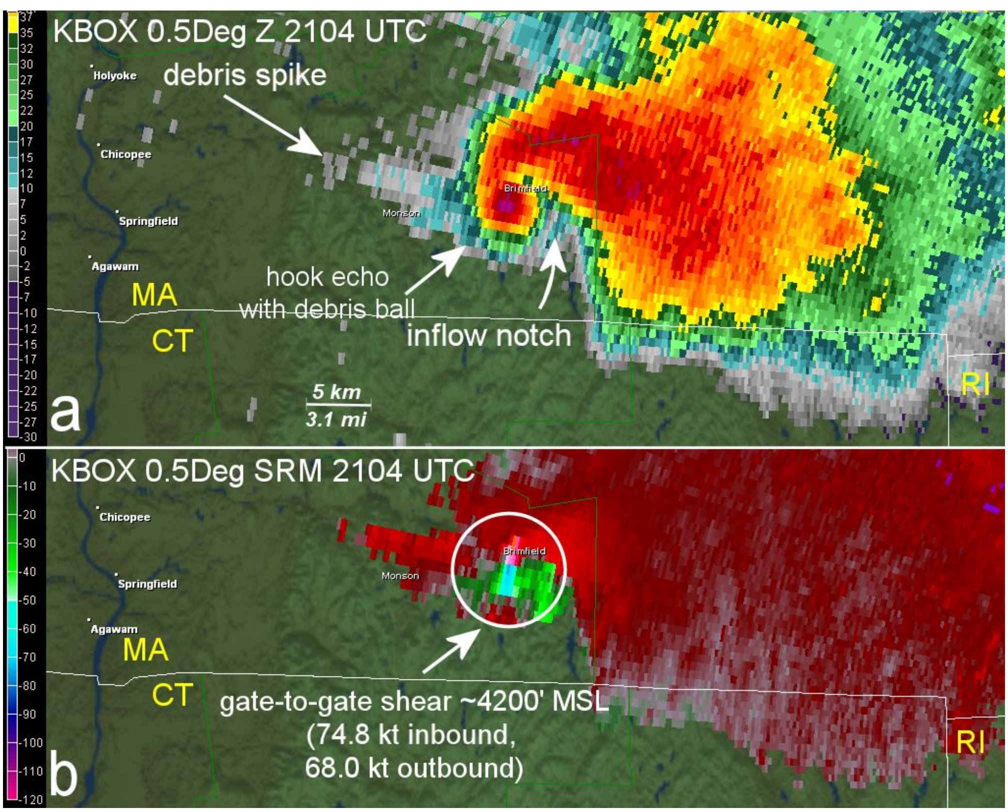

Fig 4. A tornadic supercell near Brimfield, MA during the late afternoon on 1 June 2011 as viewed from the Taunton, MA radar (KBOX). Panel (a) is radar reflectivity, and panel (b) is the storm relative velocity.

Using Modern Satellite Imagery to Examine Ice Coverage on Lake Champlain

-Matthew Clay

Did you know that one of the longest periods of recorded weather data across the North Country relates to the ice coverage across Lake Champlain? To be more specific, there are records dating back to 1816 monitoring the ice coverage across Lake Champlain and determining whether the Lake became fully ice covered. While satellite imagery didn't exist in the 1800s, the dedication of numerous observers through the decades made it possible to keep tabs on lake ice conditions.

Period	Recorded By
1816-1871	U.S. Weather Bureau Climatological Record Book with citations from Burlington Free Press clippings.
1872-1886	Charles E. Allen
1886-1906	Cooperative Weather Observer Mr. W. B. Gates
1906-Present	U.S Weather Bureau/National Weather Service

Table 1. *A history of Lake Champlain Ice Observations from 1816 to present.*

In the past, judging whether Lake Champlain was ice covered or not was determined via two methods. The first being the cessation of commercial shipping traffic with the second being full ice coverage on the broad lake from Burlington directly west/northwest to Port Kent, NY as observed from the Batter Park overlook. Nowadays, we take a more scientific approach to examining the ice conditions using the increasing number of satellites that have been launched into orbit. As you can see in Table 2 (below), satellite technology has been increasing quickly over the past decades with better and better imagery available every year.

Satellite	**Date Became Operational**	**Resolution**
GOES 13	April 14, 2010	1 kilometer/15 minutes
GOES 15	December 6, 2011	1 kilometer/15 minutes
MODIS Terra	February 24, 2000	250 meters/once per day
MODIS Aqua	July 4, 2002	250 meters/once per day
GOES 16	December 18, 2017	1 kilometer/5 minutes
GOES 17	February 12, 2019	1 kilometer/5 minutes
Radarsat-2 (SAR)	April 27, 2008	250 meters/scheduled in advance
Sentinel-1A/1B	April 3, 2014/April 25, 2016	400 meters but down to 5 meters at times/Every 2-4 days

Table 2. *Recent list of notable satellites, operational dates and spatial/temporal resolutions. Bold indicates the satellite is currently operational*

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Figure 1. MODIS pass from March 24, 2019 showing the lake ice on Lake Champlain has begun to deteriorate. The high resolution imagery allows us to see areas of open water (blue), lake ice (white) and rotting late ice (gray). Images like this come in twice a day from the MODIS constellation.

With each new generation of satellite technology, new ways of viewing images from space have developed. For example, most users are familiar with visible, infrared and water vapor imagery. Did you that GOES 16 and GOES 17 now have 16 channels instead of 5 channels that the previous generation of GOES had? These new developments give researchers and operational meteorologists a new ways of looking at the earth from space.

We are now going to look at several different satellite imagery to show how lake ice was monitored for the 2018-2019 winter season. Our typical go-to imagery is the MODIS Terra/Aqua satellite constellation. These have the best combination of temporal (time) and spatial (area) resolution being at 250 meters and 2 images a day when using both satellites. The high resolution imagery makes it easy to pick our areas of new ice, older ice and even rotting ice as the top of the ice begins to melt as seen in Fig. 3.

One caveat to using visible imagery is that cloud cover can block out what is actually going on at the surface. This tends to be the case more often than not across the North Country as we are known for many days of cloudy skies. This is where "active sensors" can come into play. An active sensor sends out a radar beam and from there is able to detect features based on scattering and refracting of the beam. In the case of satellite imagery, it allows us to see through the clouds.

The radar sends out a beam, penetrates clouds and shows us where rain is falling. One of the few active sensor satellites that can be used for ice analysis is Radarsat-2. This satellite comes equipped with a synthetic-aperture radar (SAR) that penetrates clouds based on its wavelength and creates a two-dimensional rendering of a surface feature. In the case of Radarsat-2, one of the primary objectives was to measure wind speeds over water by measuring sea spray. However, one of the other primary objectives was for measuring sea ice in the Arctic.

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If you think about conventional radar, we tend to see high reflectivities in areas of hail (ice). The same can be said for sea/lake ice. When the radar beam penetrates the clouds, strong reflectivities are sent back up to the satellite which denotes the areas of ice coverage. While Radarsat-2 is operated by the Canadian Space Agency, they have a partnership with NOAA to monitor lake ice on the Great Lakes. This can benefit the North County as Lake Champlain can often be seen on the eastern extent of the imagery taken of Lake Ontario as seen in Figure 4.

By zooming in on Lake Champlain (Figure 2), we are able to see a lot of detail and many different colors on Lake Champlain. The resolution for this image is 1 kilometer but the raw image has resolution as low as 250 meters. This resolution allows us the ability to pick out different ice types just like the visible imagery shown in Figure 1. The advantages of this type of imagery are the high level of detail and the ability to pass through clouds. However, a big downside to SAR imagery is that it's scheduled in advance and is not a routine product.

These are just a few of the every growing supply of satellite images available at our disposal. There are still many other tools not listed in this article, including the super hi-resolution imagery provided by the Sentinel-1a and 1b constellation. With continued increases in technology, our ability to observe lake ice and weather will only continue to grow which will allow us to fulfill our mission.

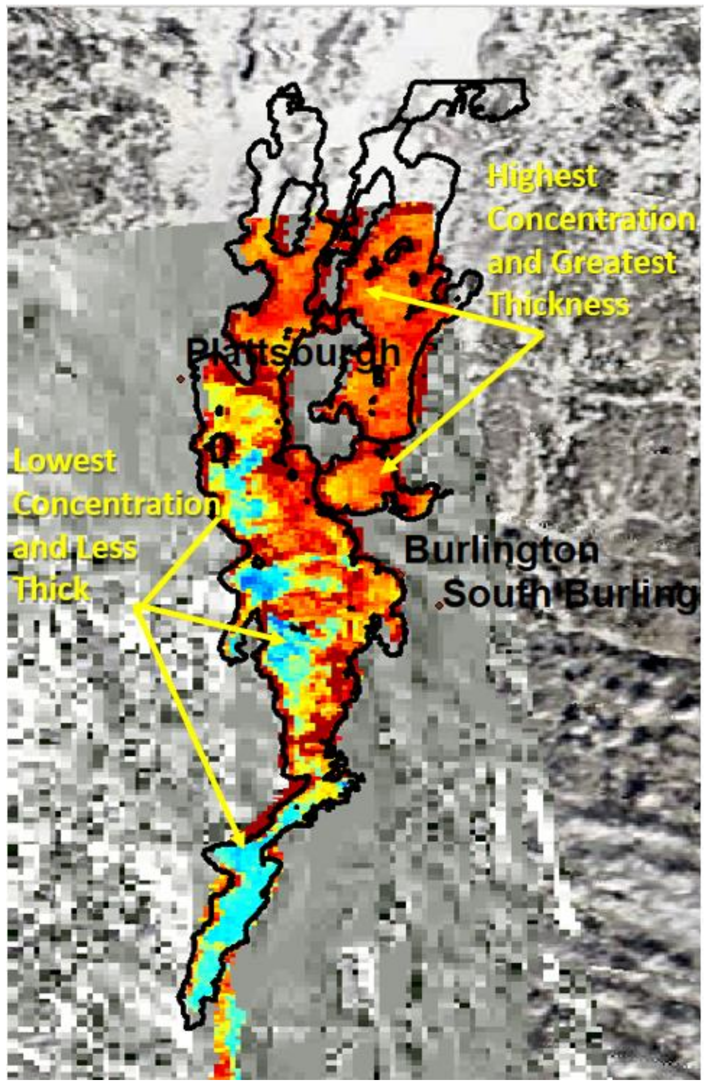


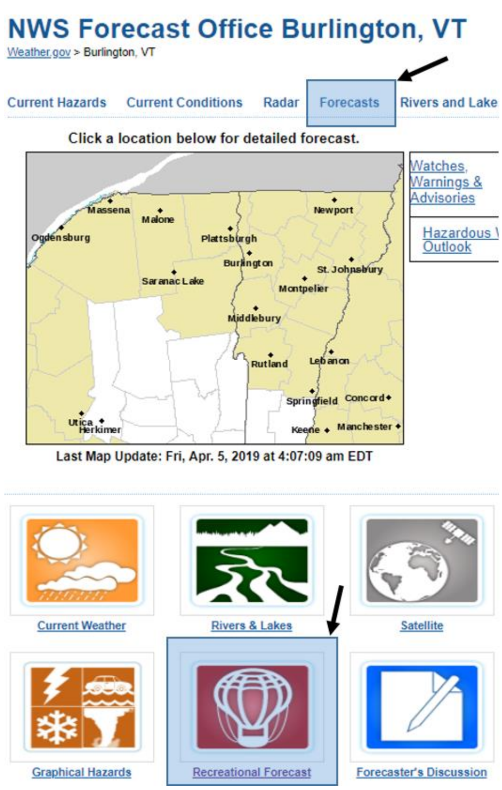
Figure 2. A close up of Figure 4 showing Lake Champlain. The reds and oranges denote greatest ice cover and thickness with the light blue denoting thin ice. Any dark blue denotes open water.

Lake Champlain Point Forecasts

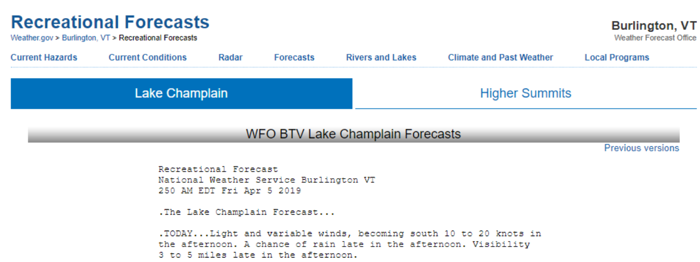
-Eric Evenson

The National Weather Service in Burlington issues daily Lake Champlain Forecasts as part of the overall Recreational Forecast. This is a general forecast for the broad lake, but did you know we provide detailed lake point forecasts? The following will show you where to find this information on our website.

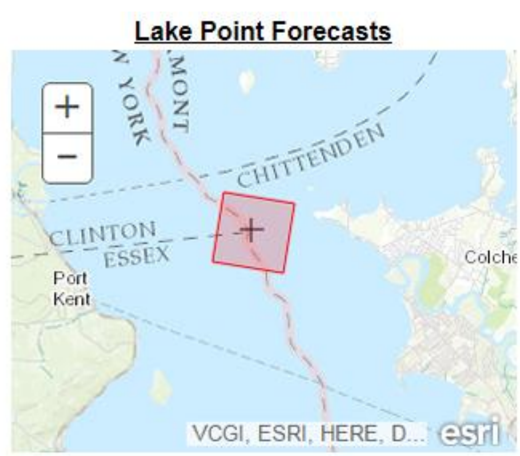
First, head to our website at weather.gov/btv or weather.gov/Burlington and either select Forecasts > Recreational above our forecast map or click the Recreational Forecast icon below the forecast map.



You will now be on the Recreational Forecast Page and should see the general Lake Champlain Forecast.



Scroll down on the page until you see the Lake Point Forecasts image. Go ahead and click it.



You are now on the Lake Champlain Point Forecasts page.

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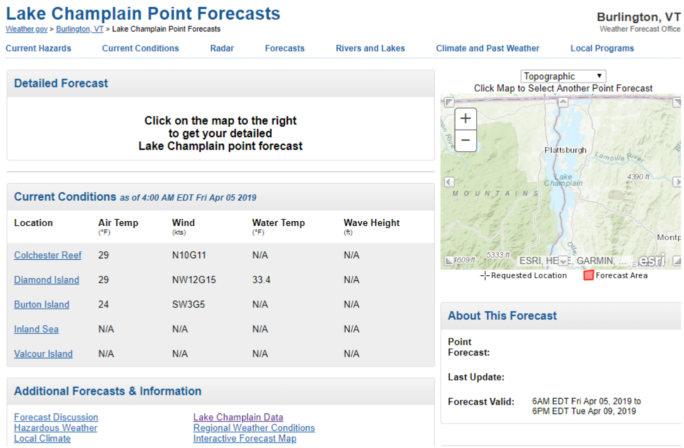
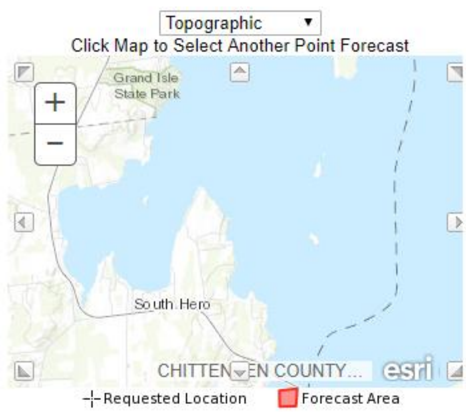
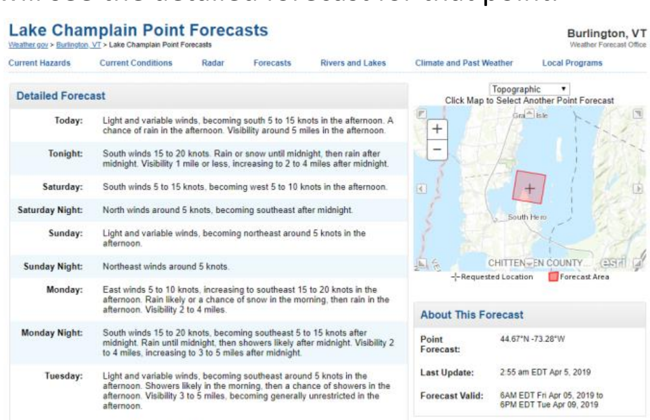


You will now utilize the map on the right hand side of the page. Zoom in on the map using a mouse or the +/- controls on the map. You can also left click and hold the mouse down to drag the map to the location you seek. For this example we are zooming into a location near South Hero.



Once you have the map the way you want it, simply clip the point in the water you are interested in and you will see the detailed forecast for that point.



You now have a detailed forecast for the area on the lake you are most interested in. If you would like to bookmark the Lake Champlain Point Forecasts page to go directly to it in the future please use the following link: https://www.weather.gov/btv/lake_point

The Four Seasons

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We Need Your Storm Reports!

Please report snowfall, flooding, damaging winds, hail, and tornadoes. When doing so, please try, to the best of your ability, to measure snowfall, estimate hail size, and be specific as to what damage occurred and when. We also love pictures!

For reports, please call:
(802) 863-4279
Or visit:
http://www.weather.gov/btv/stormreport

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