A Case Study of the 1-3 December 2019 Record Snow Event Across the NWS Albany, NY Forecast Area

Photo credit: Alicia Bentley

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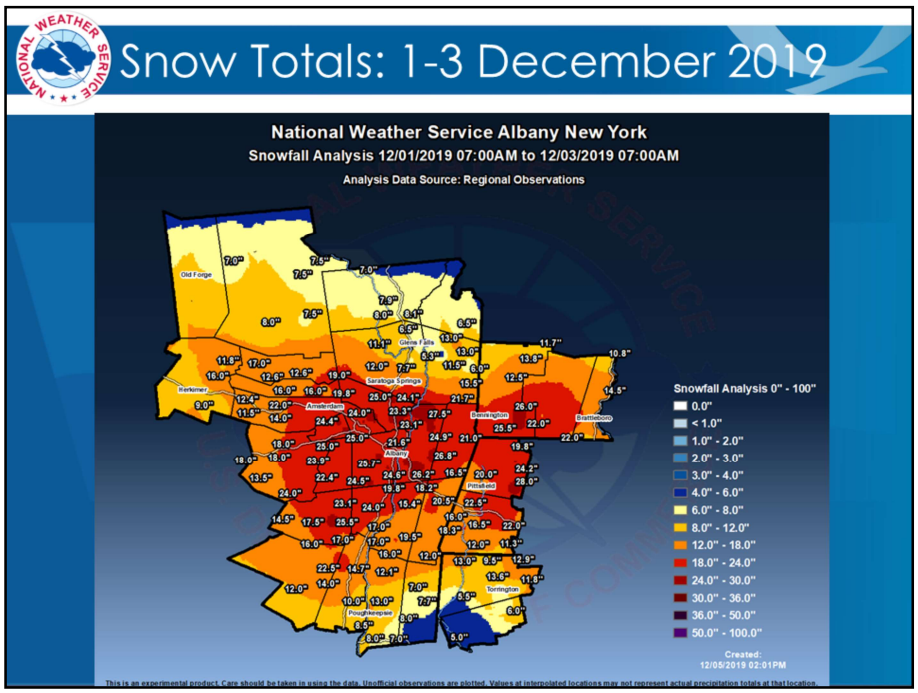
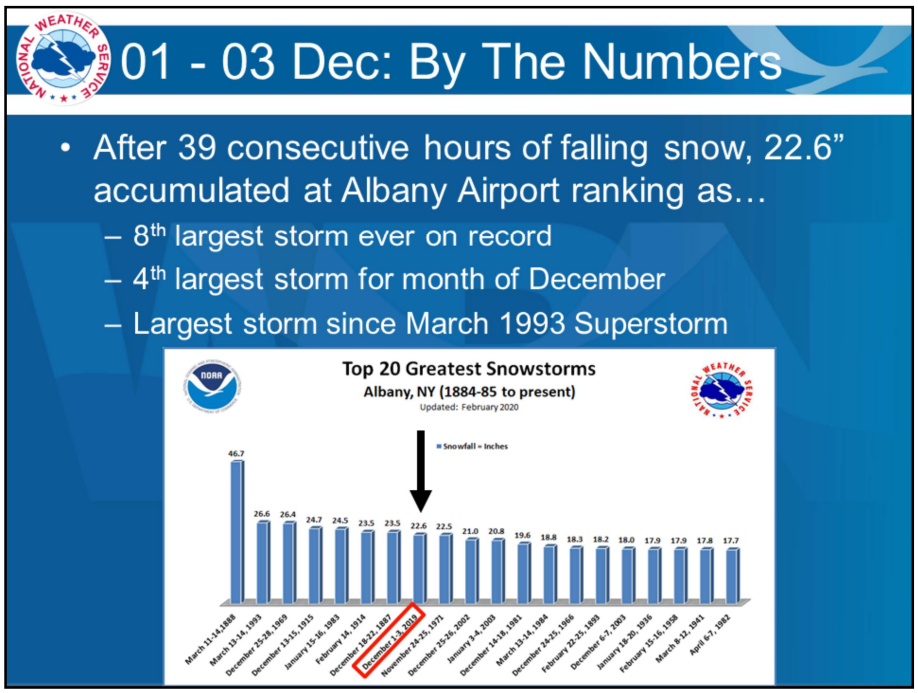
Motivation

- A significant early-season, long duration winter storm affected the Northeast U.S. 1-3 December 2019.
- Snow totals averaged 20-28 inches around the Capital District which is a third of normal seasonal snowfall.
- First round of snowfall (“phase 1”) over performed across eastern NY and western New England, impacting roadways over the busy holiday weekend along with delays and cancellations at Albany International Airport and schools.



Here is an overview of the storm total snowfall across eastern NY and western New England. The highest amounts (greater than 20 inches) were concentrated in and around the Capital District. Lower amounts occurred in the mid-Hudson Valley and parts of NW CT where snow changed to sleet, freezing rain and plain rain. Lower amounts also occurred in the Upper Hudson Valley and northern areas of Herkimer and Hamilton County which were on the northern edge of the precipitation shield.

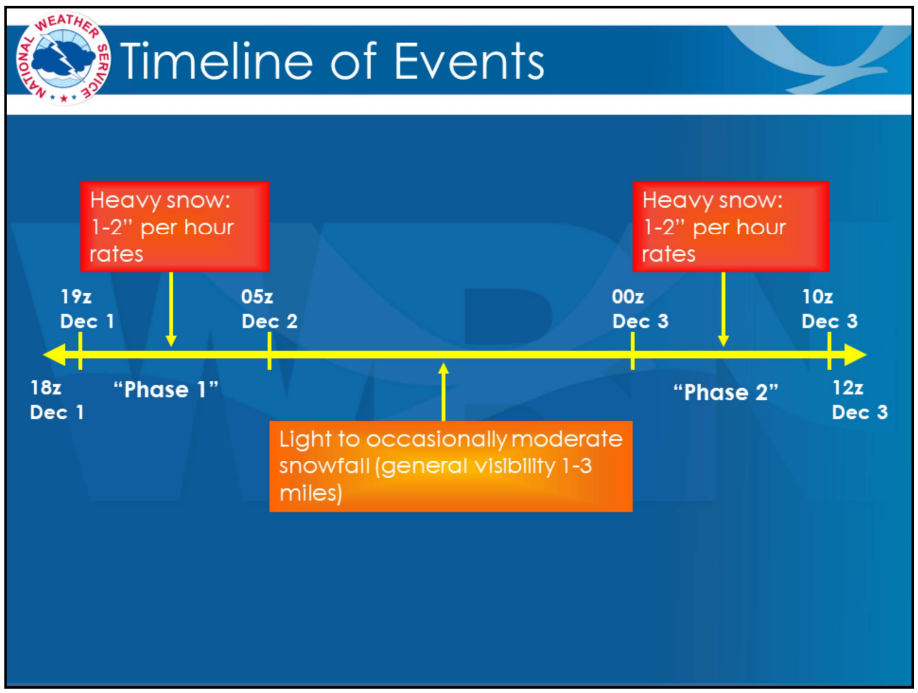


The 22.6" of snow at the Albany Airport was split into the following amounts for each day:

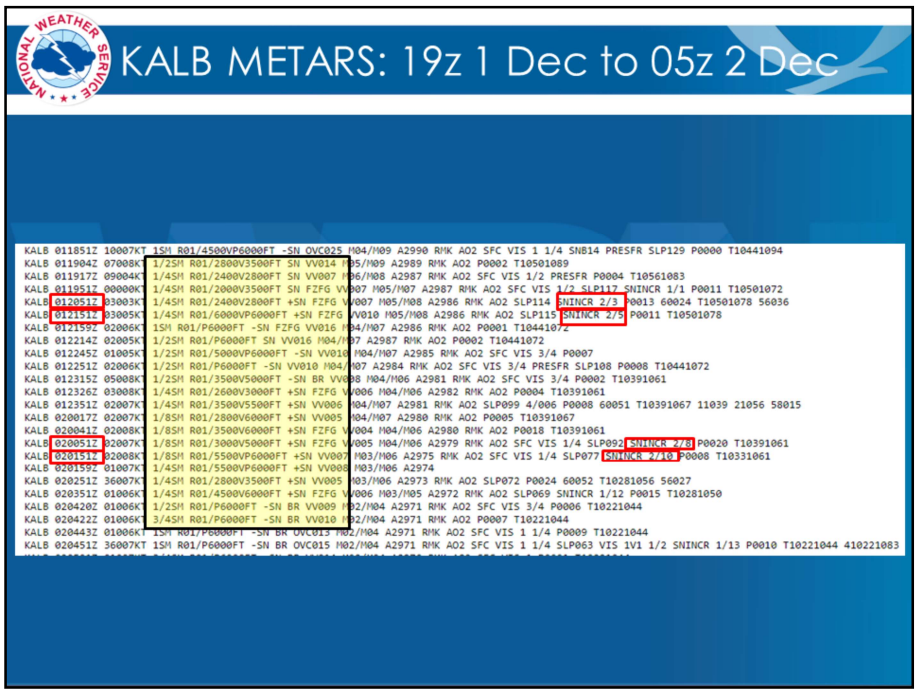
1) 01 Dec 2019: 13.3 inches (1.29 inches of liquid); fell in the last 10 hours of the day

2) 02 Dec 2019: 6.8 inches (0.60 inches of liquid); majority fell in the last 6 hours of the day

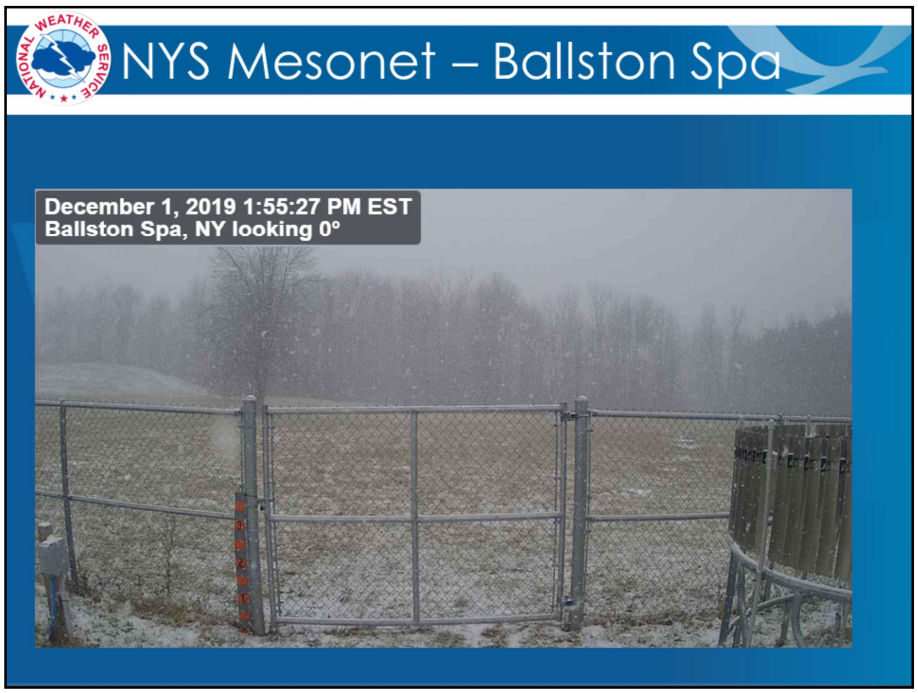
3) 03 Dec 2019: 2.5 inches (0.20 inches of liquid); all fell within the first 6 hours of the day



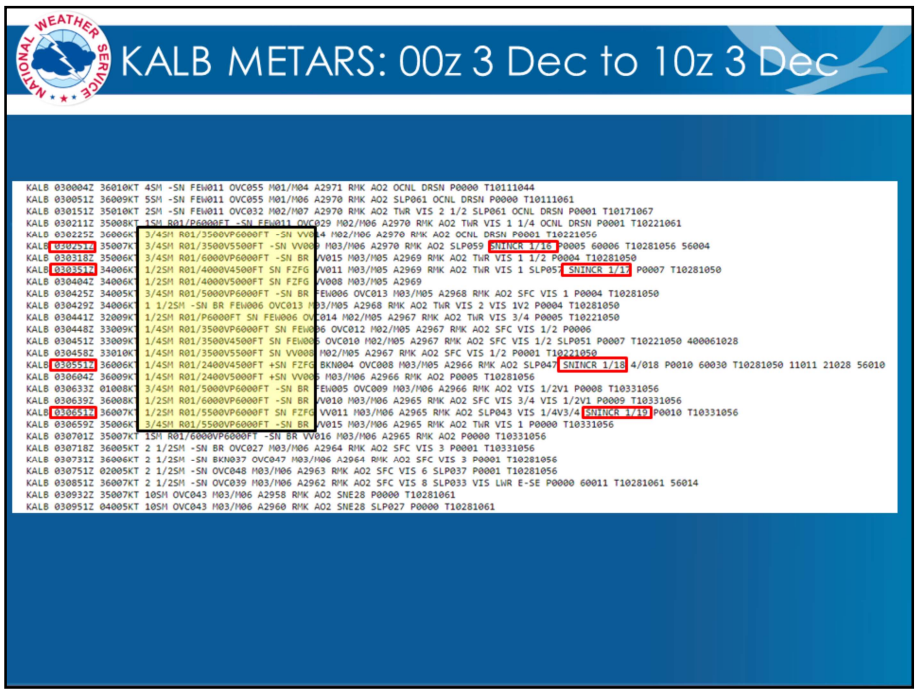
The majority of the snow accumulations occurred in two separate phases. “Phase 1” occurred between 19 UTC 01 Dec to 05 UTC 02 Dec where snow rates of 1-2 inches per hour were common. Lighter to occasional moderate snow then fell from 05 UTC 02 Dec until 00 UTC 03 Dec. Snow picked up again between 00 UTC 03 Dec until 10 UTC 03 Dec (“phase 2”) when 1-2 inches per hour snow rates were common again. Snow ended across the region by 12 UTC 03 Dec.



This is a list of the METAR observations from KALB (Albany International Airport) during “Phase 1” from 19 UTC 01 Dec to 05 UTC 02 Dec. The main feature to point are the rather persistent low visibilities of ¼ of a mile or less during periods of moderate to heavy snow. Impressively, there were 4 hours in which snowfall rates reached 2 inches per hour. By 05 UTC 02 Dec, 13 inches of snow was already on the ground which was close to the NWS Albany predicted overall storm total for Albany, NY…and there was still one more day of snow left to go!

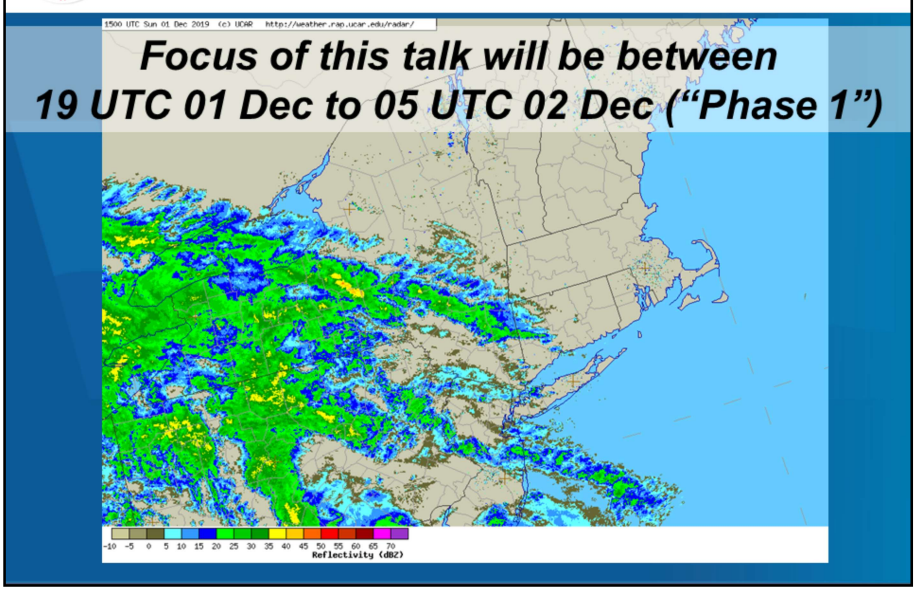


This is a still image of the snow falling at Ballston Spa, New York (Saratoga County) at 1:55 PM on 01 Dec 19 courtesy of the New York State Mesonet network. Notice large dendritic snowflakes falling and efficiently accumulating on the ground. Snow began about 30-60 minutes before this image was taken.



This is a list of the METAR observations from KALB (Albany International Airport) from 00 UTC 03 Dec to 10 UTC 02 Dec or “Phase 2”. While not as intense as “Phase 1”, there was still a 4-hour period of persistent moderate to heavy snow with visibilities generally ¼ to ¾ of a mile. There were 4 hours of 1 inch per hour rates with a snow depth of ~19 inches soon before the snow came to an end. It is important to note that the 19 inch snow depth included some compaction of the previous snow that fell and thus did not reflect the ‘storm total snowfall’.

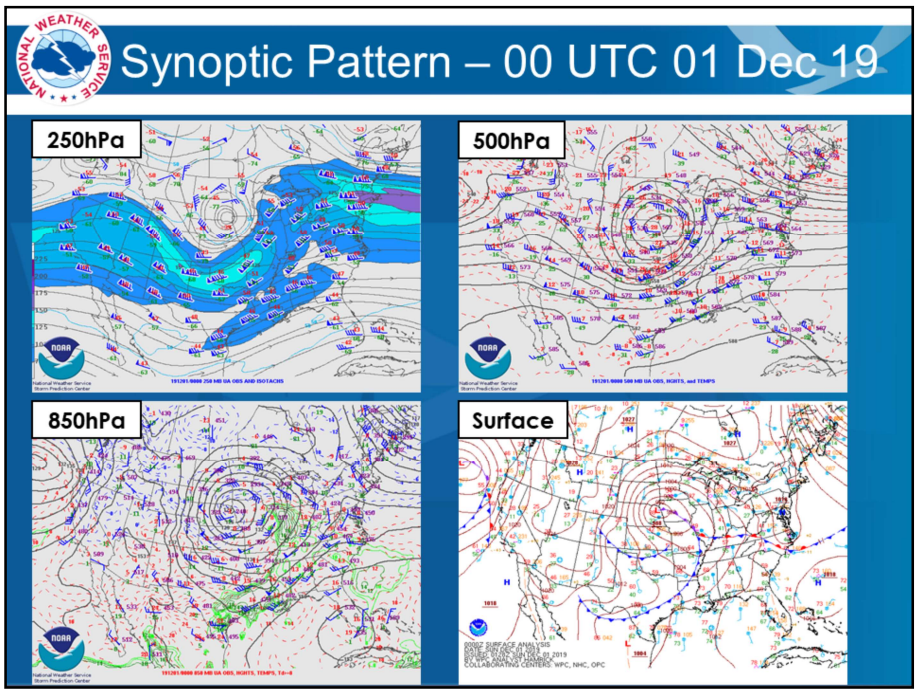
Radar


1500 UTC Sun 01 Dec 2019 (c) UCAR http://weather.rap.ucar.edu/radar/
Focus of this talk will be between
19 UTC 01 Dec to 05 UTC 02 Dec ("Phase 1")
-10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Reflectivity (dBZ)

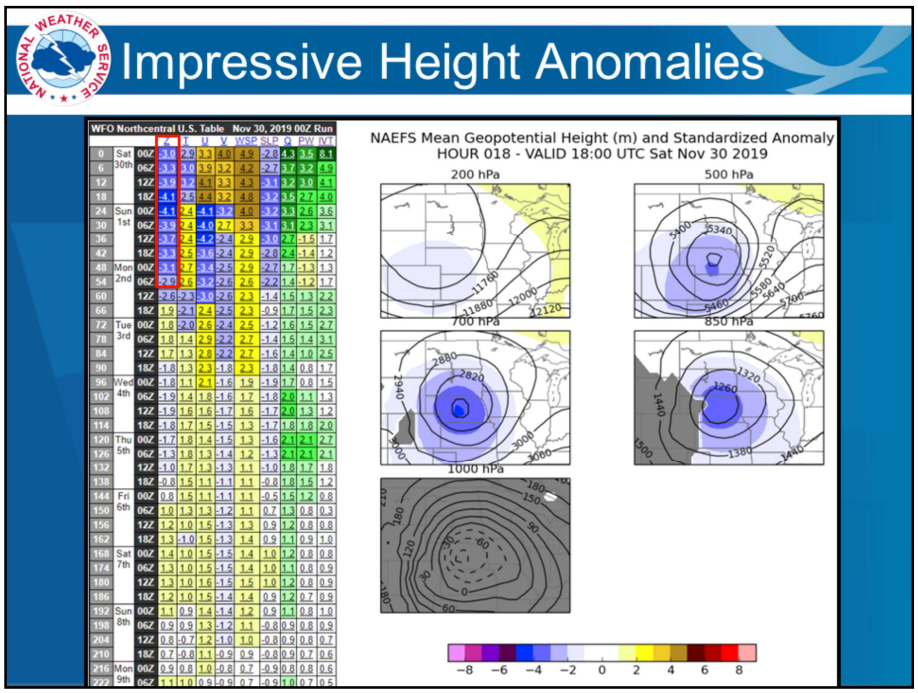
Important Questions to Answer

What led to the overachieving snowfall during “phase 1”?

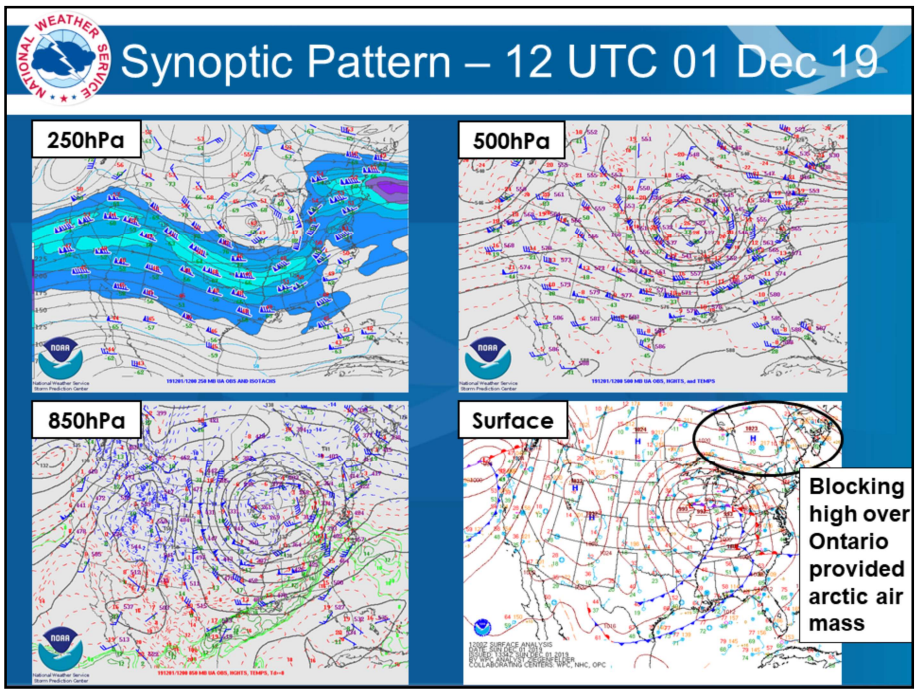
- Was it purely a result of tremendous isentropic lift?
- Were more features at play given its unique synoptic set-up?



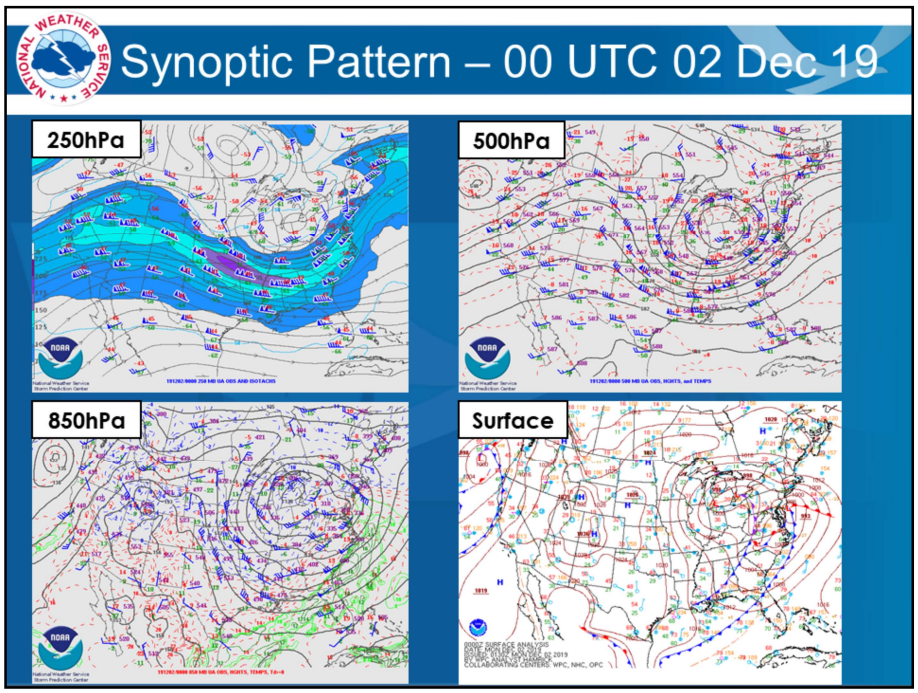
A very impressive cut-off initially brought hurricane force winds to the Pacific Northwest and Oregon's lowest pressure reading on record over the Thanksgiving holiday. It then traversed the CONUS while maintaining its intensity as shown above in the 00 UTC 01 Dec upper air plots. Notice it is cut-off up to 250hPa with a strong fetch of moisture streaming northward of the Gulf of Mexico. Off the New England coast, notice a pronounced 250hPa jet streak with a second jet streak developing south of the cut-off low.



To illustrate the anomaly of the cut-off low, notice the height fields (represented by column Z above) were 3 to 4 standard deviations below normal on the 00 UTC 30 Nov run of the NAFES valid at 18 UTC 30 Nov. Wow!



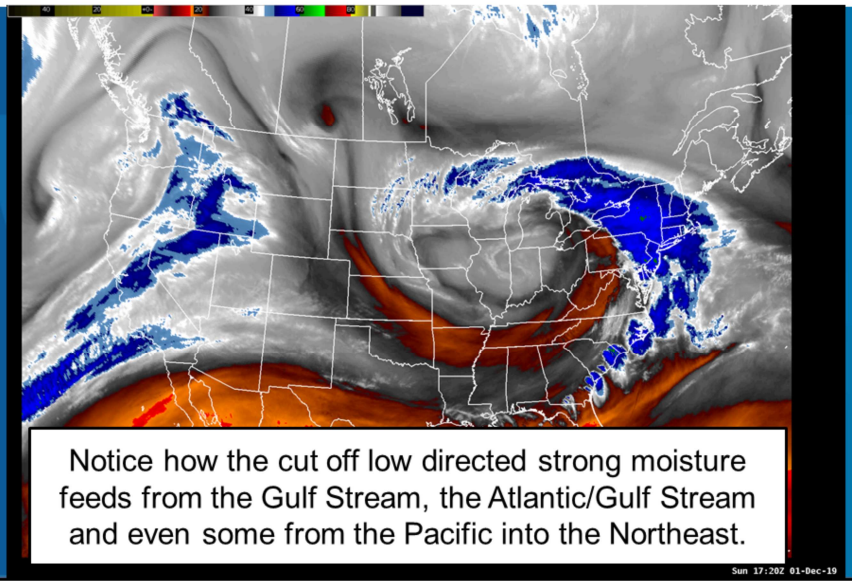
12 hours later at 12 UTC 01 Dec, our cut-off reached the Midwest with a ~1025hPA blocking high over Ontario. The blocking high led to a chilly and dry air mass over the Northeast before the cut-off low arrived towards 18 UTC 01 Dec. Also notice that the strong southwesterly flow ahead of the cut-off low pumped moisture from both the Gulf of Mexico and the still warm waters of the Southeast coast. Lastly, a dual jet structure is clearly evident on the 250hPa image with the Northeast positioned in the equatorward facing entrance region of the jet off the New England coast and in the poleward facing exit region of the jet over the Mississippi Valley.

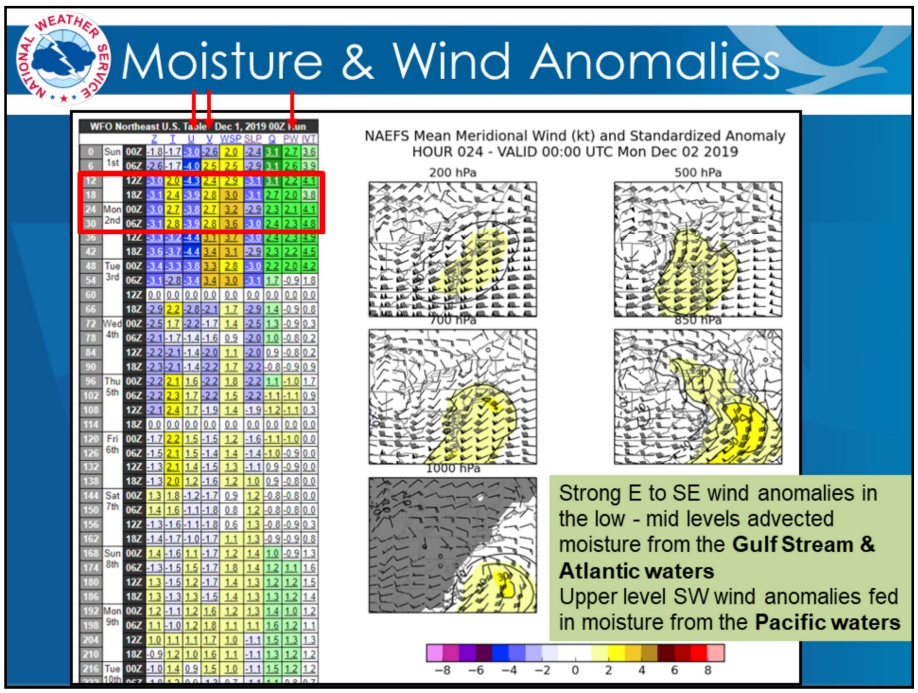


Two main sources of lift resulted in the prolonged period of heavy snow that was ongoing over eastern NY/western New England at 00 UTC 02 Dec. First, the impressive dual jet structure resulted in incredible upper level diffluence and strong forcing for ascent. Second, the 45-50kt mid-level jet directed warm/moisture rich air from the Gulf of Mexico and Atlantic waters over the Gulf Stream into the Northeast. With a cold and dry Canadian air mass in place firmly at the surface (see page 26 for the ALY sounding), this resulted in incredibly strong isentropic lift.

Also take note of how slow the cut-off low has progressed since 12 UTC 01 Dec. In just 12 hours, it only traveled from the Midwest to the Ohio Valley.

GOES16 Mid-Level Water Vapor

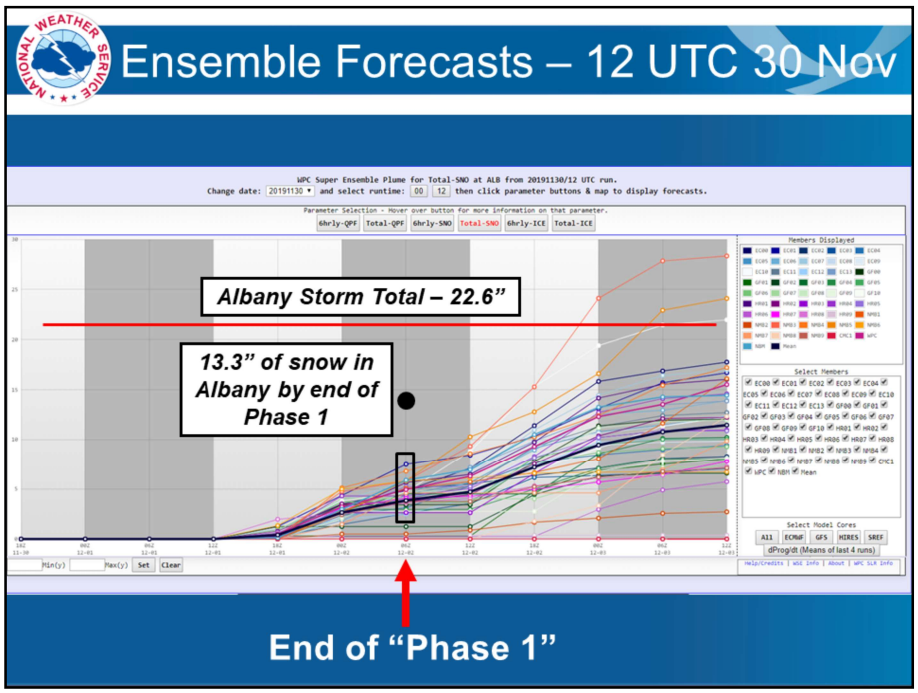




00 UTC 01 Dec run of the NAFES valid at 00 UTC 02 Dec show southeast wind anomalies (especially at 850hPa) ranging 3 to 4 standard deviation above normal. Such a strong southeasterly fetch resulted in high moisture anomalies.

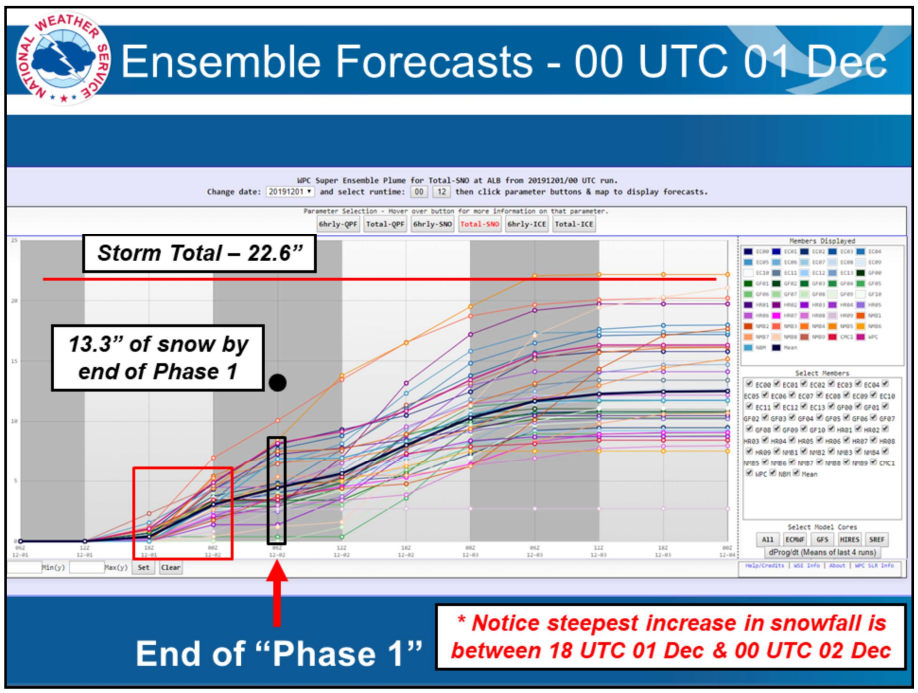
Synoptic Conclusions

- West to east tracking cross-country cut-off low with incredibly impressive height anomalies very slowly progressed into the Great Lakes by 01 Dec 2019
- A dual jet structure led to very strong forcing for ascent over the Northeast
- Anomalous E to SE winds persisted leading to a warm conveyor belt of moisture rich air from the Gulf Stream and Atlantic being directed into the Northeast.
- Very slow progression of cut-off low allowed favorable dynamics and isentropic lift to *pummel* the Northeast with very heavy snow for nearly 12 hours.



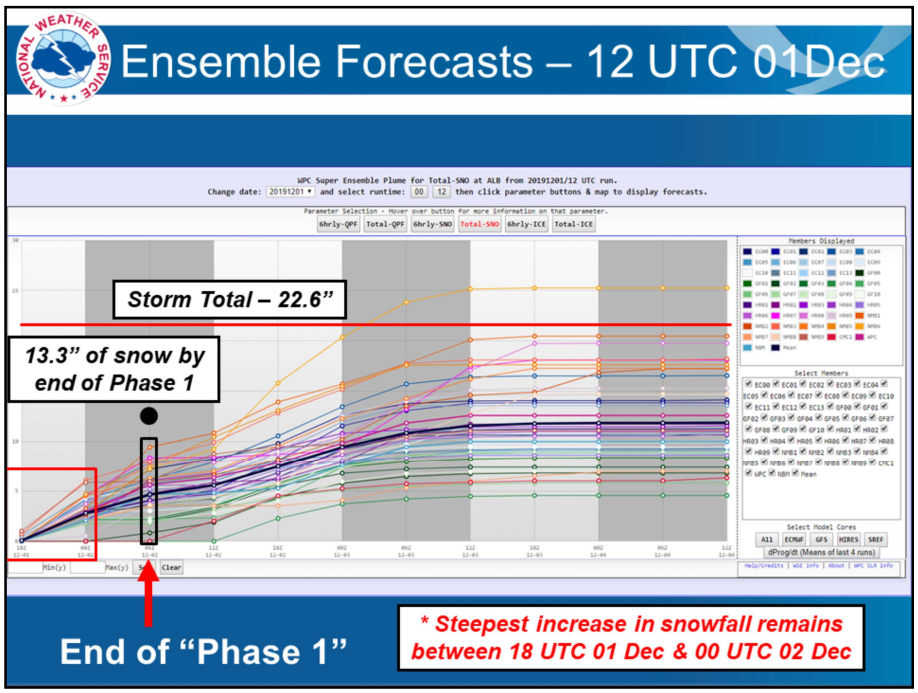
This graphic shows model ensemble snowfall forecast from the 12 UTC 30 Nov run (the day before the event began). The majority of the models indicated between 4 and 8 inches of snow would fall by 06 UTC 02 Dec (or the end of “Phase 1”). The guidance underestimated amounts by 5-10 inches.

Many of the members were also well below what would be the overall storm total for this event. A few of what most forecasters at the time deemed outlying members ended up being close to the final snowfall totals (or even over-predicted).



This graphic shows model ensemble snowfall forecast from the 00 UTC 01 Dec run (the evening before the event began). The members continued to predict less snow than what actually occurred during “Phase 1” (3-8 inches). This would have been a situation to follow the outliers as the highest member predicted ~10 inches in this run. Also, note the steep increase in model predicted snowfall between 18 UTC 01 Dec and 00 UTC 02 Dec, which was an indication of heavy snow.

The large spread among the members regarding the final storm total snowfall continued with the highest member predicting ~22 inches.



This graphic shows model ensemble snowfall forecast from the 12 UTC 01 Dec run (the morning of the event). All members were still underestimating snowfall during “Phase 1” with generally 3-8 inches still predicted (little change from the previous model runs). There continued to be a steep increase in amounts between 18 UTC 01 Dec and 00 UTC 02 Dec, highlighting possible heavy snow. Notice that many of the ensemble members were tightly packed together. This usually suggests a higher confidence forecast. However, this would have been a case to deviate from the mean and follow the outliers, had their been any.

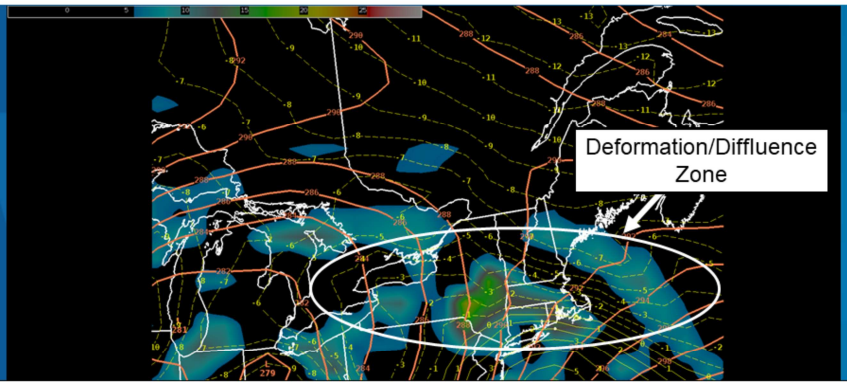
For overall storm total, the highest outlying members were still close to what would end up being the actual storm total snowfall with all other members still underdone.

Initial Forecast Messaging

- Very heavy snow including 1-2 inch per hour snowfall rates will arrive early afternoon and last through early evening on December 1, 2019 as tremendous isentropic lift overspread eastern NY/western New England. Good Forecast!

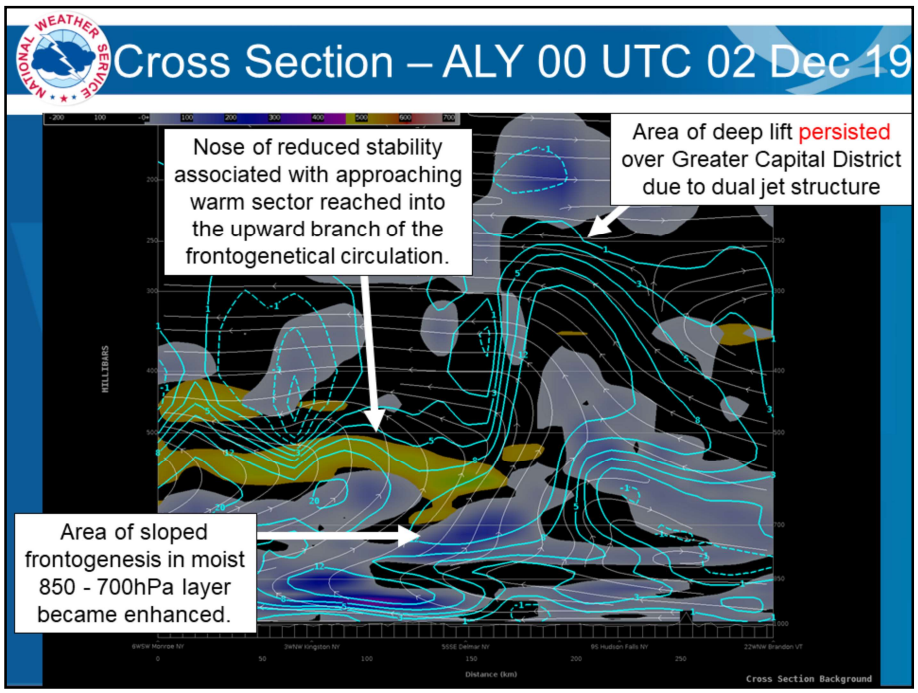
- Evening Expectations…
  - Warm nose would intrude the region, sending the mixing line northward up the Hudson River.
  - Mixing line expected to reach near or just south of the Capital District and act to reduce snowfall rates by early evening. NWS included potential for some brief sleet to reach as far north as Albany.
  - Included potential for E to SE winds to downslope off the Taconics/Greens/Berkshires and thus reduce snow totals in some areas. What went wrong?

00 UTC 02 Dec 19: Heavy Snow Continues



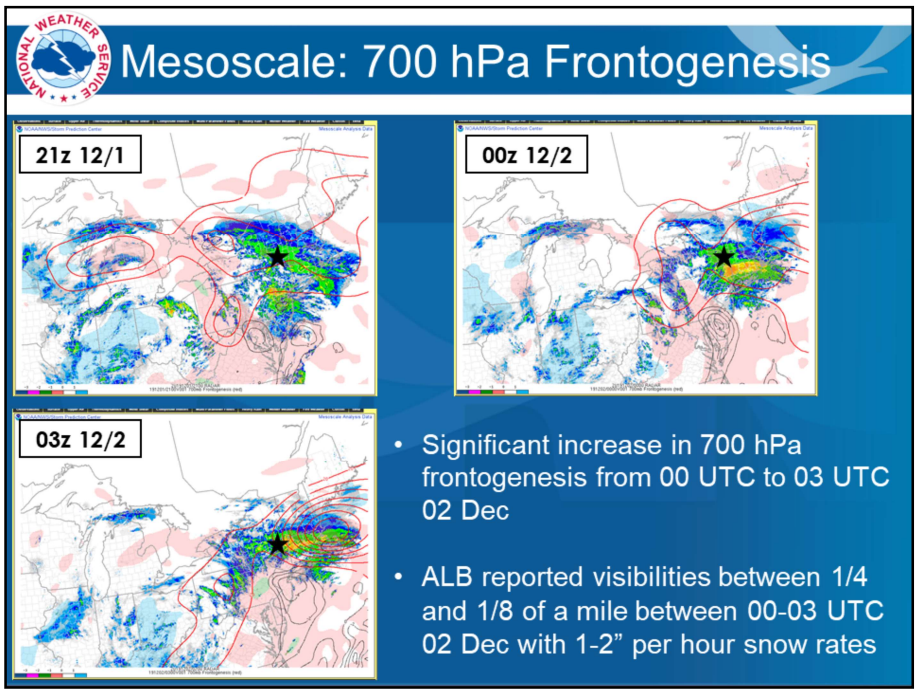
Total deformation over the Capital Region increased as the broad area of diffluence ahead of the slow moving closed low in the presence of a blocking high **persisted**. Mid-level temperature gradient tightened across the axis of dilation, enhancing frontogenesis

The warm conveyor belt **continued** to be directed perpendicular to 850-700 hPa temperature gradient well after 00 UTC 02 Dec. As the warm/dry sector approached, the mid-level winds increased & enhanced the lift across the region of strong frontogenesis.

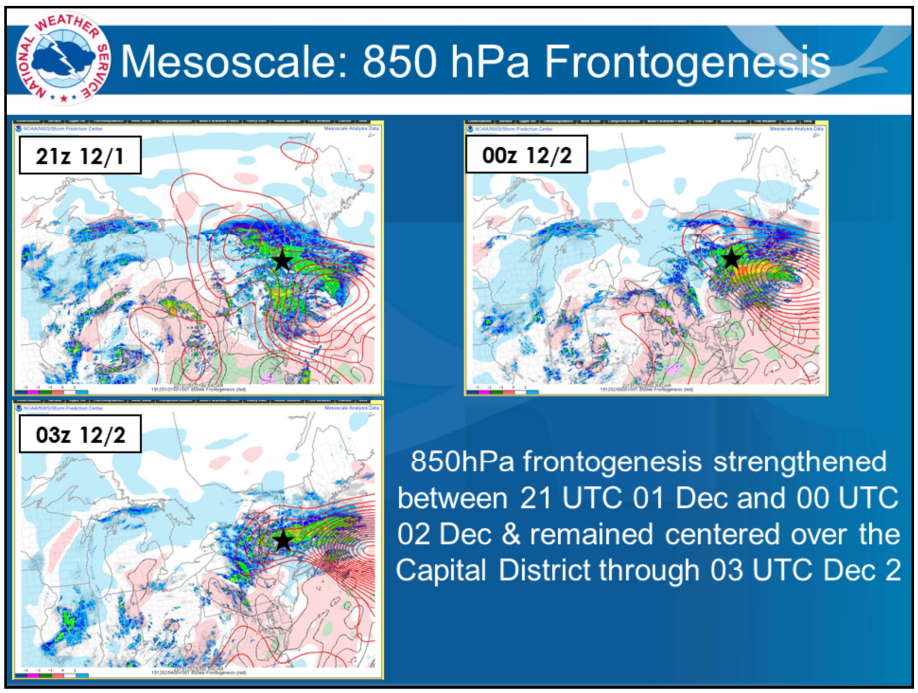


Above is a cross section taken perpendicular to the thickness lines at 00 UTC 02 Dec spanning between Monroe, NY (located in Southeast NY) and Brandon, VT (located near Rutland, VT). Plotted are reduced stability or negative theta-e lapse rates in yellow shading, positive frontogenesis in blue shading, omega in light blue contours and ageostrophic circulation in white streamlines.

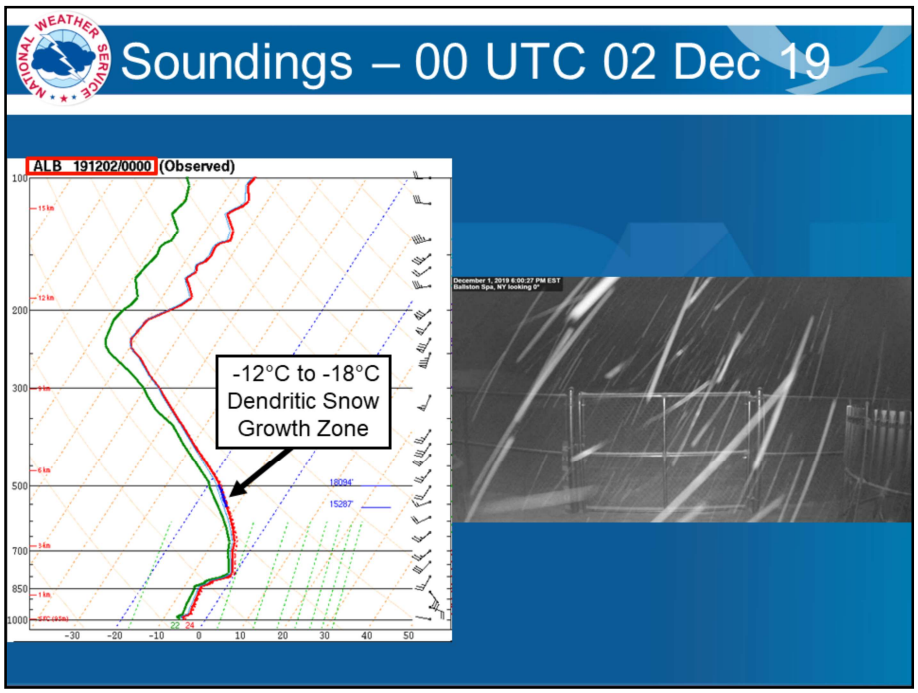
During this period, the warm nose began intruding northward up the Hudson Valley. We can see signs of its intrusion as the tongue of reduced stability advanced northward. The advancing warm nose changed snow to wintry mix in the mid-Hudson Valley, Catskills and NW CT. As the reduced stability neared the Capital Region, it also reached the upward branch of the frontogenetical circulation where the 850-700hPa layer was also saturated. Thus, it acted to enhanced mid-level frontogenesis (noticed the frontogenesis is sloped) and also neared the region of enhanced/deep omega due to the dual jet structure. As a result, a second period of moderate to heavy snow developed and impacted the Capital District from 00 UTC to 05 UTC Dec 2. This second period of heavy snow was poorly forecast by model guidance.



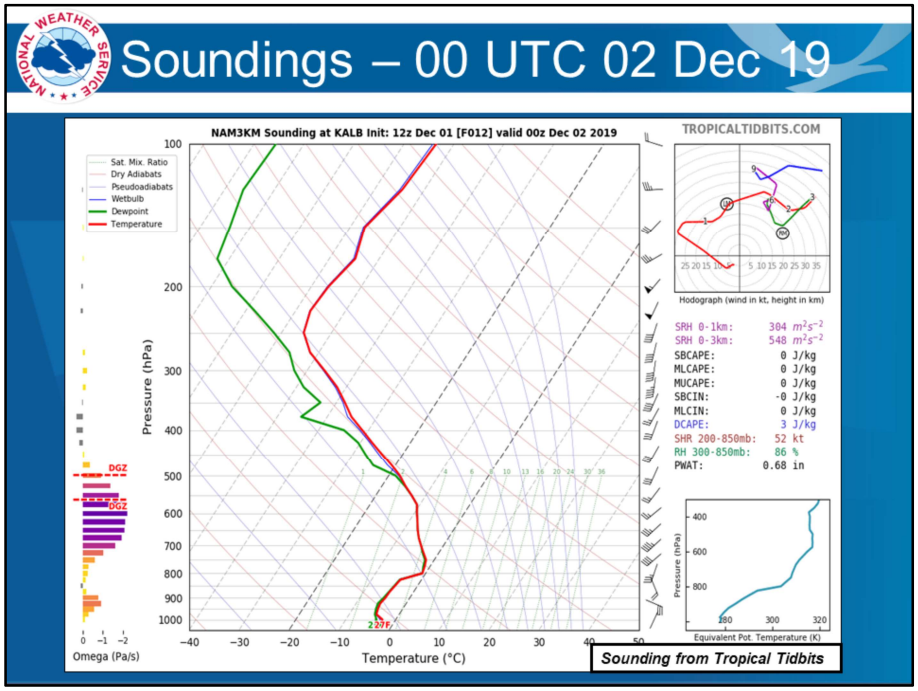
These images show 700 hPa frontogenesis in the solid red lines (an indicator of possible heavier, banded precipitation). You can see from 21 UTC 01 Dec to 03 UTC 02 Dec, the Capital Region was in an area of strong frontogenesis, indicating that moderate to heavy snowfall could occur across the region. Noticed it strengthened rapidly between 00 UTC and 03 UTC 2 Dec. During this time, visibility at the ALB airport due to heavy snow was nearly consistently between 1/4 and 1/8 of a mile with snowfall rates of 1-2 inches per hour.



These images show 850 hPa frontogenesis in the solid red lines (an indicator of possible heavier, banded precipitation). Similar to the previous slide, strong areas of frontogenesis were located over the Capital Region from 21 UTC 01 Dec to 03 UTC 02 Dec, which lined up with where heavy snowfall occurred.



The pronounced cold wedge from the arctic air mass is evident on the 00 UTC ALY 02 Dec sounding. Notice the cold wedge footprint extends impressively up to 800hPa. Secondly, notice that the warm nose aloft nears the 0°C isotherm between 800-700hPa with the -12°C to -18°C dendritic snow growth zone (DGZ) near 500hPa. Despite the DGZ existing so high up in the column, an image from the NYS mesonet at Ballston Spa from 6PM 01 Dec clearly shows large dendrites falling. How?



Looking at the NAM3km model sounding image of ALY valid for 00 UTC 02 Dec, we can see that very strong omega/deep lift extended through the column up to 500 hPa as a result of the dual jet structure. In addition, despite the warm nose nearing the 0C isotherm, little if any sleet occurred in the Capital District, again likely due to the deep lift.

Lastly, notice that the boundary layers winds were directed from the east. Typically, easterly winds lead to downsloping off the Greens and Berkshires and thus a shadowing effect reduces precipitation in the Capital Region. That did not occur here. Why? The cold wedge extended so high up in the column that the isentropic lift occurred on a higher theta surface between 300-305K which was well above the terrain.

Conclusions

- Ensemble guidance trended upwards with snowfall leading up to event but even the highest members were too low for "phase 1". Members remained packed close together each model run. This may have been a case to follow the outliers, had there been any.
- Heavy snow continued well into the evening hours because…
  - Very strong and deep lift from the dual jet structure continued
  - Deformation in the diffluent zone persisted ahead of the anomalous, slow moving closed low in the presence of a blocking high. This tightened the mid-level temperature gradient and thus increased frontogenesis.
  - The warm conveyor belt continued to be directed perpendicular to the region of enhanced frontogenesis
    - The advancing warm nose introduced a region of reduced stability which also acted to enhance mid-level frontogenesis