ATMS 502 Introduction to Synoptic Meteorology Final Project:

Upstate New York snow event and coastal low

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Upstate New York snow event and coastal low case:

On 25 February 2022 a widespread 6-to-12-inch snowfall occurred across the northeastern side of the United States of New York, Massachusetts, Pennsylvania, Vermont, and New Hampshire states. This storm system produced snowfall rates of 1 to 2 inches per hour during the afternoon on the 25th, along with visibility below ½ mile at times, creating very hazardous driving conditions, especially during the evening commute. As a result of the extremely poor driving conditions a 30-car pileup happened on Interstate 89 northbound near exit 17(Milton), unfortunately one fatality occurred.

In this review we will examine the meteorological factors that produced this moderate snowfall across northern New York on 25 February 2022, including Part 1: Synoptic overview, Part 2: Large scale diagnosis: Frontogenesis, and Part 3: Science Question: Snow Bands

Part 1: Synoptic overview

At the surface level (Table 1), from 25 February 2022 00 UTC to 21 UTC, weak 1012 mb low pressure was located near coastal part of New York at 12 UTC, while strong above 1036 mb high pressure was situated over Great Plain/Central United States and intensified at 15 UTC and 18 UTC. New York state was surrounded by high pressure system during that period of time. By 12 UTC and 15 UTC, primary surface low pressure was located in the mainland of New York, followed by a secondary low in the coastal area of New York and high pressure remained surrounding New York persistently. The collision between cold air to very warm/moist air in New York area, helped to promote favorable lift for a band of warm air advection snow (Table 2). By 18 UTC, the surface low was no longer observed in the mainland of New York, but we could still see the low-pressure area located in the coastal part of New York.

In addition to surface level low, the 850 hPa analysis places most of the upstate New York in favorable frontogenesis forcing just north of a warm front and near the closed 850 hPa circulation. From Table 2 at 12 UTC, the strongest warm advection lift is near the nose of the 40 to 50 knot jet at 850 hPa and associated with the tightening thermal gradient. This produced an area of moderate snowfall with rate around 1 inch per hour and surface visibilities between 0.5 and 1 mile during the mid-morning hours on 25 February 2022.

Table 3 shows the 500 hPa on 25 February 2022 indicated a broad ridge on the Pacific Northwest that favors the formation of a wide a broad mid-level trough across the central/northern United States with potent short-wave energy located over the central Great Lakes at 12 UTC on 25 February 2022. This short-wave energy was embedded in the broad trough within a very fast/confluent flow of the atmosphere of 60 to 110 knots from the Mississippi River Valley into the Northeast United States. This energy coming from the short wave impacted the upstate New York during the afternoon on the 25 February 2022 and produced favorable synoptic scale ascent to enhance snowfall rates.

In addition to a broad mid-level trough and short wave, the 250 hPa analysis (Table 4 and Table 5) shows weak upper-level trough over the central/Northern United States and short wave over Northeastern United States emerged from the Rockies which supports the weak cyclogenesis. At 18 UTC on 24 February 2022, the Southeast and Midwest exhibited lower background Sea Level Pressure, a pre-existing frontal boundary, and a generally warmer temperature. Over the next 12 hours, a surface cyclone developed and deepened as it moved within the background southwesterly flow. A strong surface anticyclone dove southward out of central Canada, aiding in the maintenance of the shortwave trough via cold air advection. Meanwhile, warm surface air continued wrapping into the surface cyclone as it began to occlude. Around 12 UTC on 25 February 2022, the initial cyclone center weakened due to a combination of the upper-level trough overtaking it and the cyclone running into the remains of a cold air dam where high Sea Level Pressure was found.

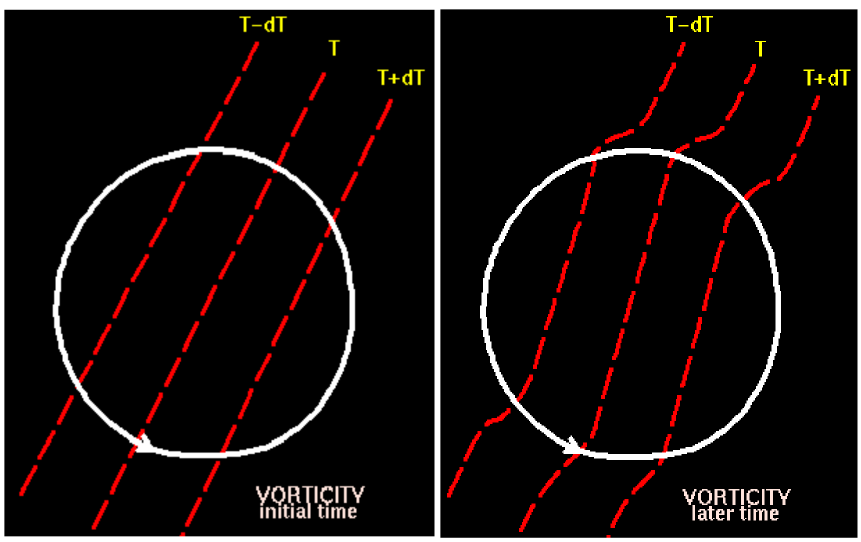
Part2: Large scale diagnosis – Frontogenesis

a) Write down frontogenesis equation and name the four terms. For each term, briefly describe the process and with a sketch, describe how that process contributes to frontogenesis.

$$F = \underbrace{\left[\frac{\partial \theta}{\partial x}\left(\frac{\partial u}{\partial y}\right)\right]}_{\text{Term A}} + \underbrace{\left[\frac{\partial \theta}{\partial y}\left(\frac{\partial v}{\partial y}\right)\right]}_{\text{Term B}} + \underbrace{\left[\frac{\partial \theta}{\partial p}\left(\frac{\partial \omega}{\partial y}\right)\right]}_{\text{Term C}} - \underbrace{\left[\frac{\partial}{\partial y}\left(\frac{d\theta}{dt}\right)\right]}_{\text{Term D}}$$

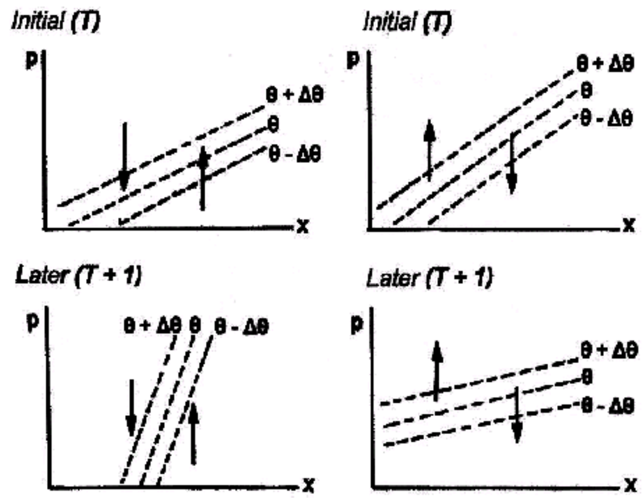
This equation displays the frontogenesis equation. Term A is the shearing term, Term B is the confluence term, Term C is the tilting term, and Term D is the diabatic term.

A. Vorticity/Shear



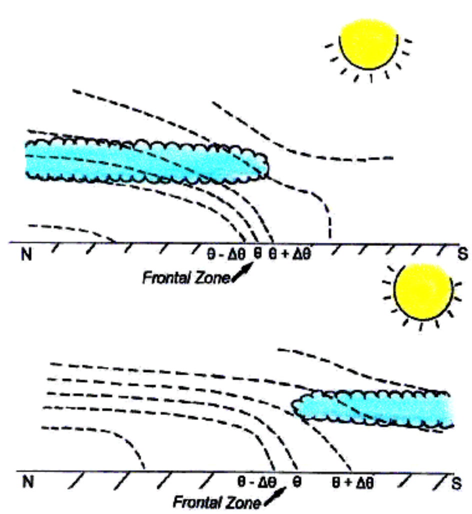
Initially the sheared wind field applied to a uniform thermal gradient. After a time, the sheared wind field acts to rotate the temperature gradient. Common example of frontogenesis from shearing deformation: in the vicinity of a cold front south of a surface low pressure area.

B. Tilting Effects



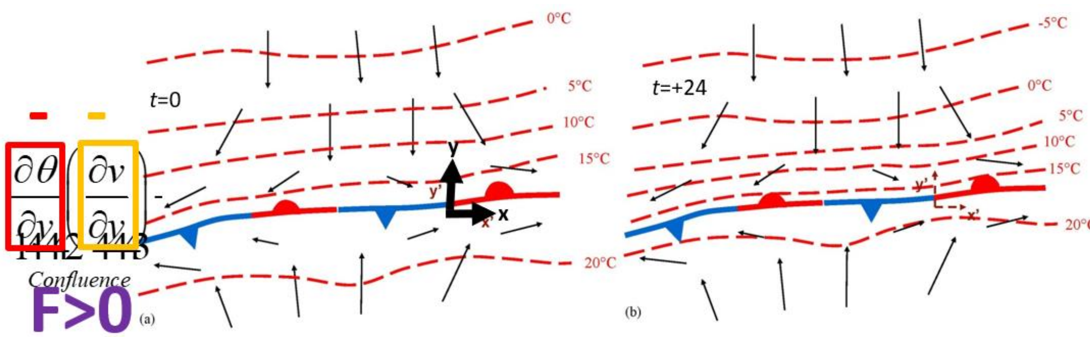
In these cases, the temperature gradient is in the vertical as opposed to the horizontal in the preceding examples. The temperature gradient is being tilting by the vertical motion field. Above (left 2 images), differential vertical motion acts to increase the thermal gradient, i.e., frontogenetically. Above (right 2 images), differential vertical motion acts to decrease the thermal gradient, i.e., frontolytically. Example of frontogenesis from tilting: Indirect thermal circulation in exit region of an upper-level jet.

C. Diabatic Heating



Diabatic Heating can act *frontogenetically* (top image) or *frontolytically* (bottom image). Top (cold air on left; warm air on right): cloud cover is limiting radiational warming on colder left side, while cloud-free warm area on right heats up. Thus, thermal gradient strengthens (frontogenetical). Bottom (cold air on left; warm air on right): the sun warms the cloud-free cold air while cloud cover limits radiational warming in the warm air mass. Thus, thermal gradient weakens (frontolytic). Small-scale low-level frontogenesis due to diabatic heating can be important in unstable environments, where the resulting small-scale frontal lift causes convective development. Example of frontogenesis from diabatic heating: Stratus clouds forming on north side of cold front.

D. Confluence



Confluence frontogenesis describes the change in front strength due to *stretching*. If the isotherms are stretching (spreading out), there is frontolysis. If they are compacting, frontogenesis is occurring. Along the front, $\frac{\partial\theta}{\partial y}$ is negative. Here $\frac{\partial v}{\partial y}$ is also negative, giving a positive contribution to F. This means along the front, confluence acts in a frontogenetical sense.

b) From Part 1, pick a couple of times where the fronts appear reasonably strong. Make plots of 1000hPa (or other heights such as 925, 850 or 700hPa) heights, temperature and winds over a zoomed in area encompassing the storm. Note where the fronts are located.

Ans: Attached in Table 6 (We chose 1000 and 850 hPa). Table 6 shows the overlays of geopotential heights, temperature and winds over the United States at 1000 and 850 hPa from 00 to 21 UTC on 25 February 2022. From 1000 hPa, we notice how the horizontal temperature gradient increases dramatically from 03 UTC to 18 UTC. At 03 UTC, the temperature over coastal Binghamton and Albany was just around five degrees colder than over the coastal New York city.

By 12 to 18 UTC, there was a 10–20-degree Celsius difference over the same area. The frontal system appears strongest at 12 UTC where the temperature gradient strengthening the fastest over time. The front is in the northeast of the low-pressure system. Originally there were two pressure system observed from 9 to 15 UTC located in mainland of New York states and coastal New York states, but at 18 UTC these two low level systems were unified into one low-pressure system over the coastal are of New York bringing warm-moist air favorable for the snowstorm in our case.

From 850 hPa plots of geopotential heights, temperature, and winds over the United States, we also notice how the horizontal temperature gradient increases dramatically from 03 UTC to 18 UTC. At 03 UTC, the temperature over coastal Binghamton and Albany was just around 25 degrees colder than over the coastal New York city. By 12 to 15 UTC, there was a 20–30-degree Celsius difference over the same area. Area of favorable 850 hPa frontogenesis forcing just north of warm of our warm front, near the nose of the 40 to 50 knots jet. The front is also in the northeast of the low-pressure system. Unlike the 1000 hPa plots, there were only one pressure system observed from 9 to 18 UTC located in mainland of New York states bringing warm-moist air favorable for the snowstorm in our case. Note that in each case, winds are converging near the frontogenesis area.

(c) For this same level, plot Frontogenesis these same two times. Assess the strength of the frontogenesis associated with any fronts of this cyclone.

Table 7 shows 1000 and 850 hPa, low-level frontogenesis on 25 February from 00 UTC to 21 UTC. The frontal system appears strongest at 12 UTC where the temperature gradient strengthening the fastest over time produced favorable condition to our snowstorm. The front is in the northeast of the low-pressure system. Originally there were two core frontal system observed from 12 to 15 UTC located in mainland of New York states and coastal New York states, but at 18 UTC these two-core low level frontal systems were unified into one core low level frontal system over the coastal are of New York.

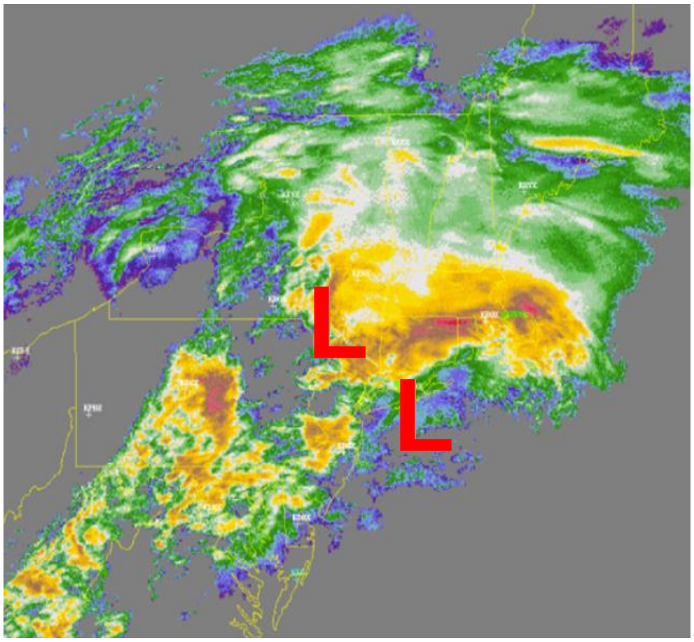
Unlike the 1000 hPa frontogenesis plots that shows two core frontal system associated with our two low-pressure system, at 850 low-level frontogeneses, there was only one core frontal system in compliance with one low-pressure system observed from 9 to 18 UTC located in mainland of New York states. The frontal and low-pressure system at 850 hPa located more to the west than 1000 hPa frontogenesis. This shifting of location is due to the tilting effect of the frontogenesis.

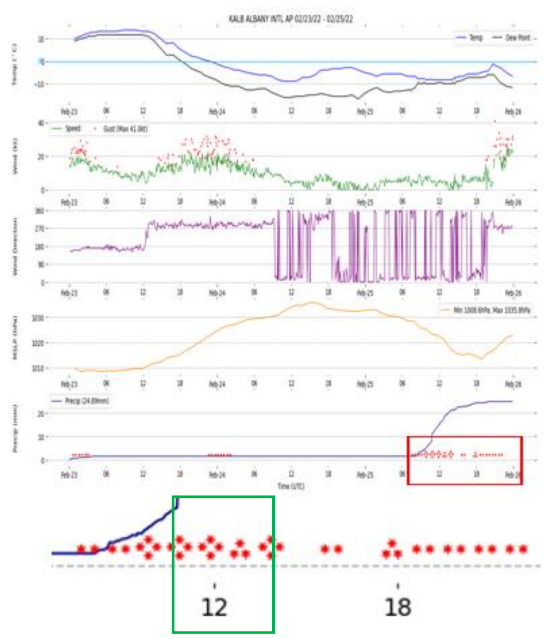
(d) Does the model produce strong vertical motions in association with regions with strong frontogenesis? Do observations of clouds and precipitation relate to these regions (if present) of strong vertical motions and frontogenesis?

Table 8 shows 1000 and 850 hPa at 12 UTC, low-level frontogenesis, overlayed with vertical motions. From these two levels we can see an upward motion and winds are converging near the frontogenesis area. When winds converge in the low level, air piles up and is thus forced upward. This upward motion is what produces the bands of heavy rain and snow we expect in frontogenesis setups.

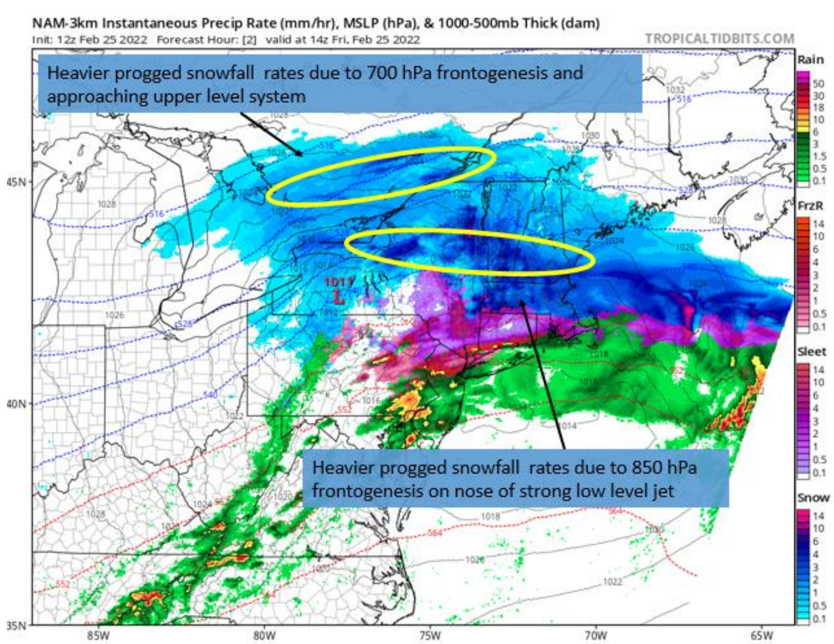
Part 3: Science Question: Frontogenesis and Snow Bands

The figure below (left) shows the mosaic of radar reflectivity at 12 UTC on 25 February 2022. From the radar band we can see that in the upstate New York there are precipitation mixed with snow at 12 UTC. Precipitation bands are generally observed on the north to northwest of the weak low-pressure system. From the real data observation obtained (right figure) from the Albany International Airport also shows that at 12 UTC there was a heavy snow continuous at time of observation. As the surface temperature below 0 degree Celsius at that time, it is cold enough to support the precipitation fall as bands of very heavy snow.

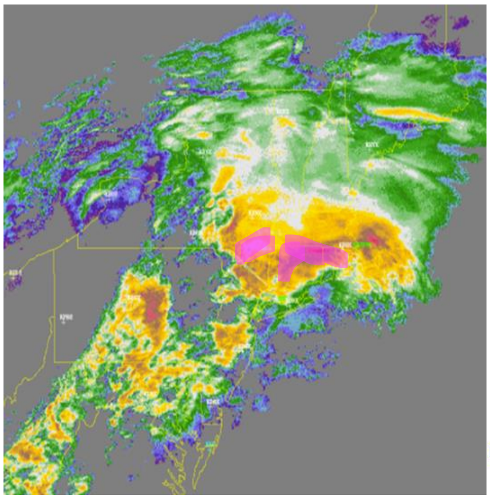




The figure below shows the NAM-3km instantaneous precipitation rate and type of precipitation initialized at 12 UTC on 25 February 2022, valid for 14 UTC on 25 February 2022. This clearly shows the higher probability of snowfall rates (darker blue) over eastern NY associated with initial surge of warm advection lift at 850 hPa associated with 850 frontogenesis, while a secondary area of enhanced snowfall occurred into northern NY.



The figure below shows that the area we highlighted as experiencing strong frontogenesis is also experiencing heavy precipitation. Even within a weak o surface low, frontogenetical forcing exist resulting in banded precipitation and significant precipitation rates. The heavy precipitation bands were oriented parallel to the isotherms and frontal zone.



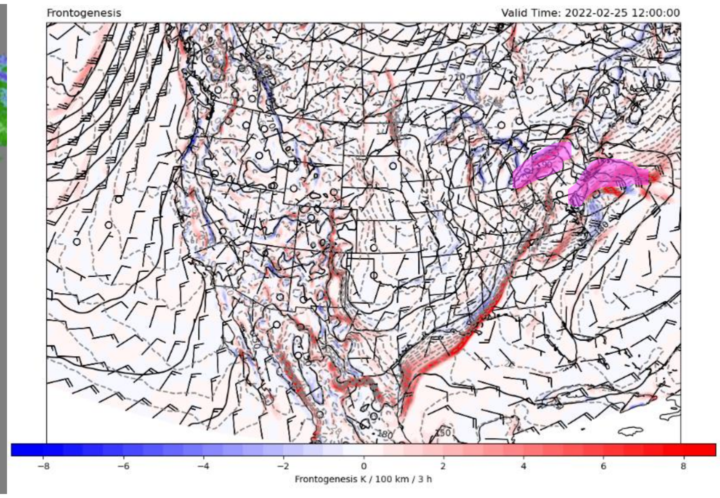


Table 1. Mean Sea Level Pressure, Temperature, and Wind on 25 February 2022

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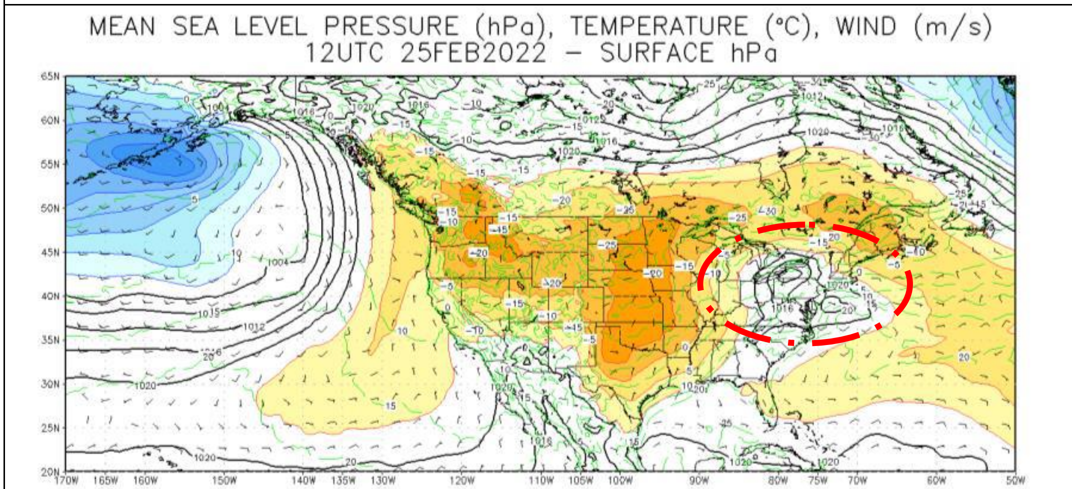
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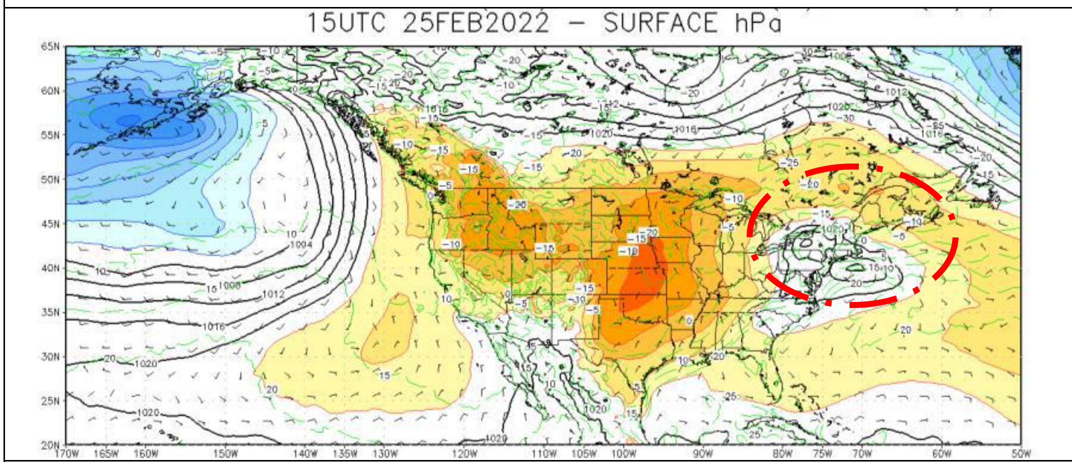
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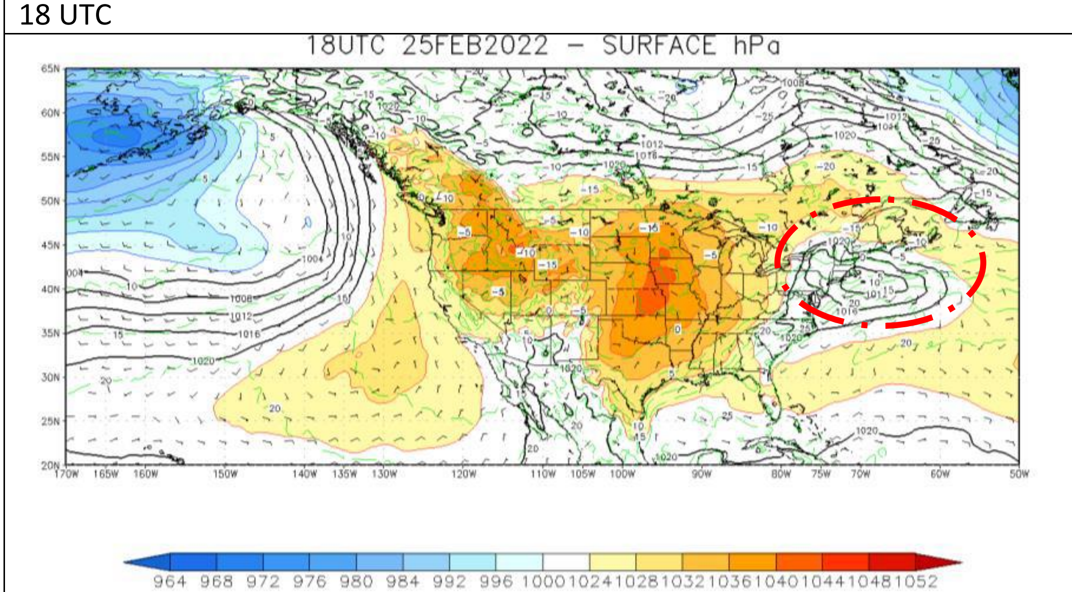

Table 2. 850 hPa Geopotential Height, Temperature, and Wind on 25 February 2022

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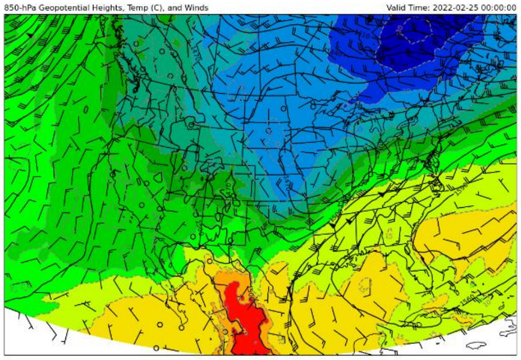
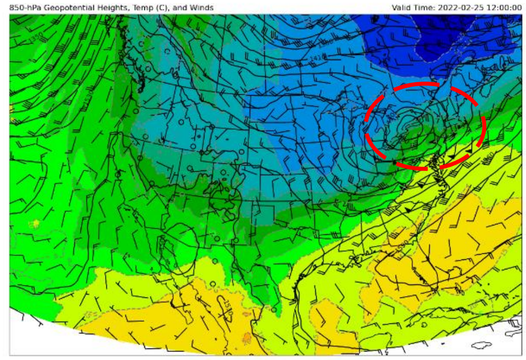
<tr><td>
</td><td>
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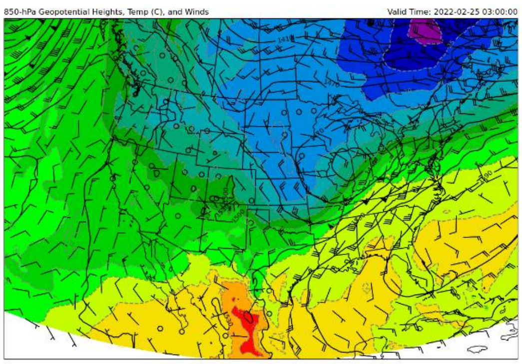
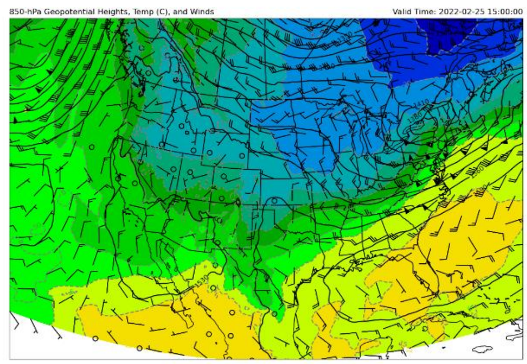
<tr><td>
</td><td>
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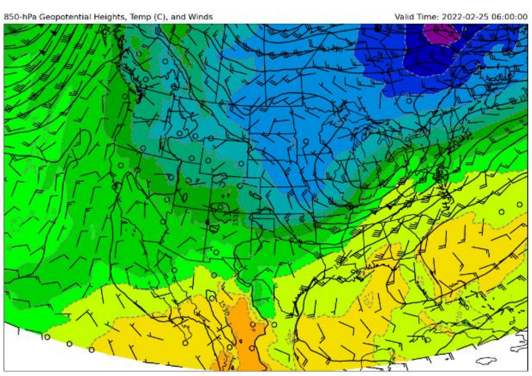
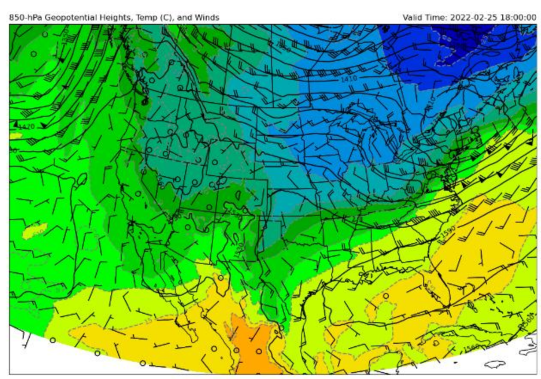
<tr><td>
</td><td>
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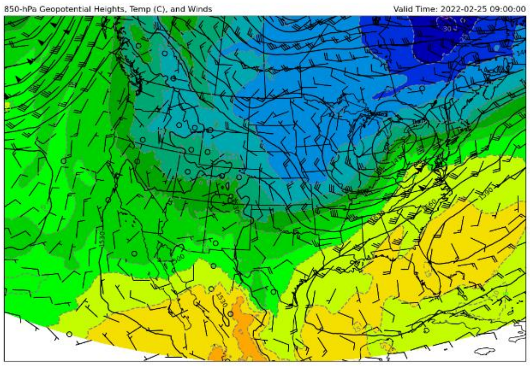	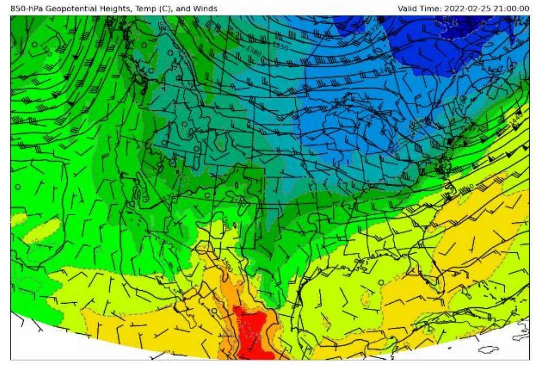

Table 3. 500 hPa Relative Vorticity, Geopotential Height, and Wind on 25 February 2022

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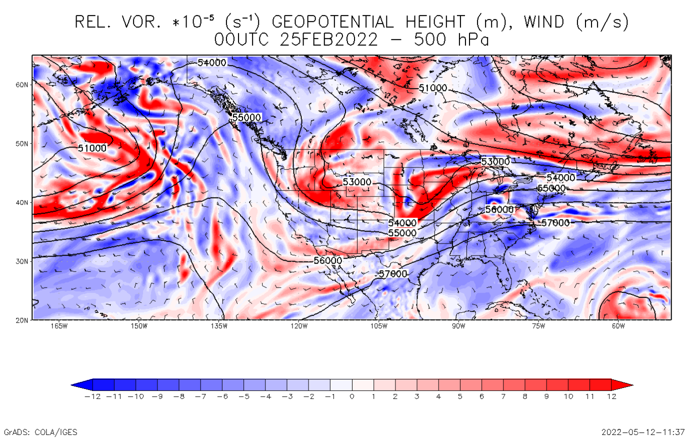	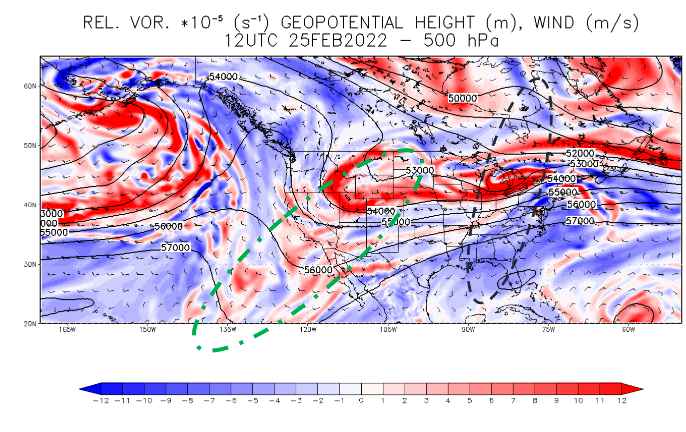
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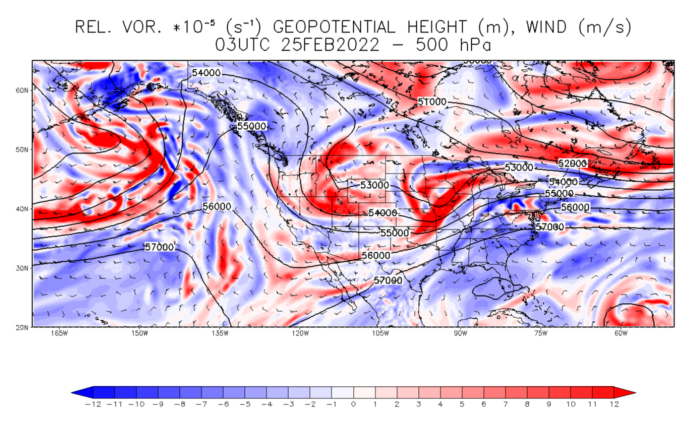	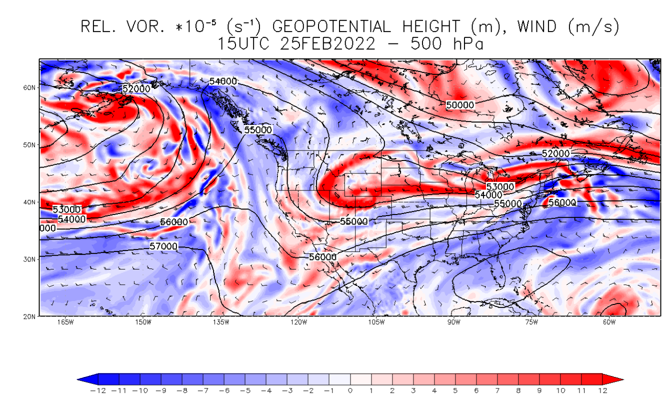
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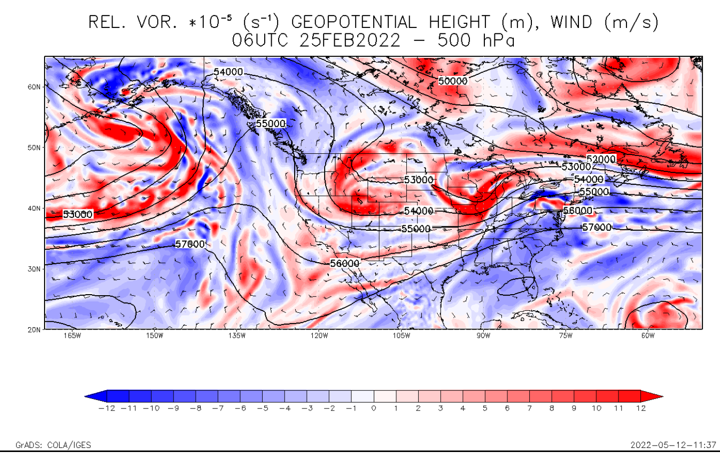	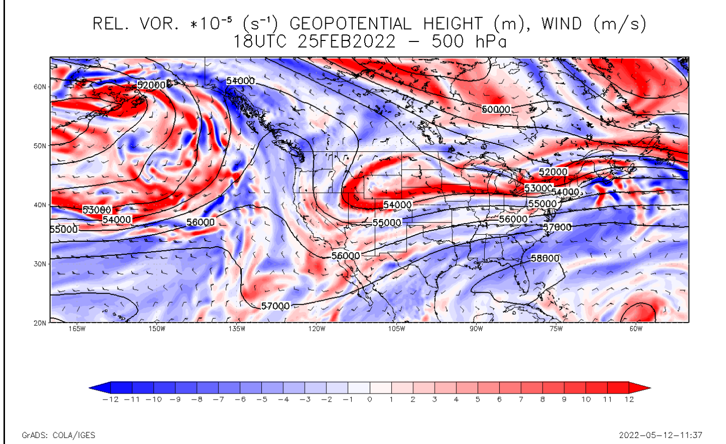
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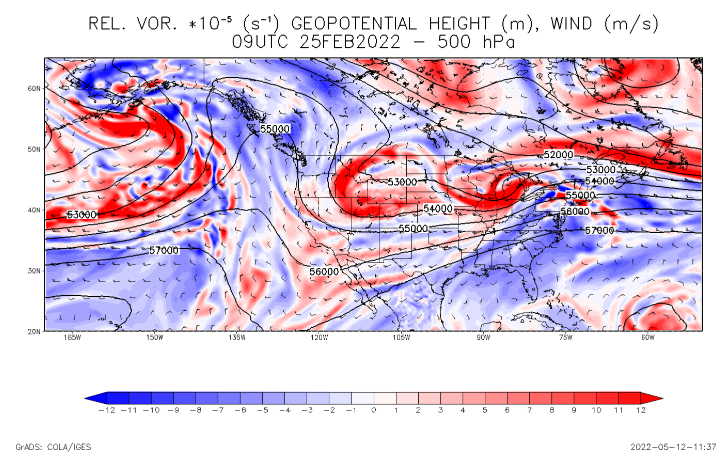	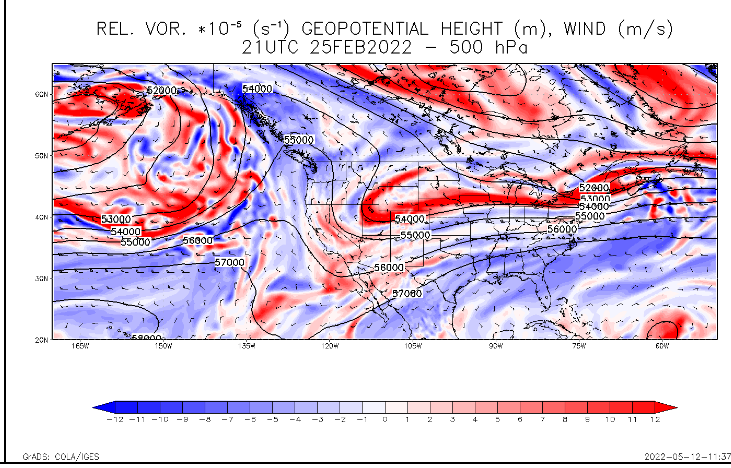

Table 4. 250 hPa Geopotential Height and Wind on 25 February 2022

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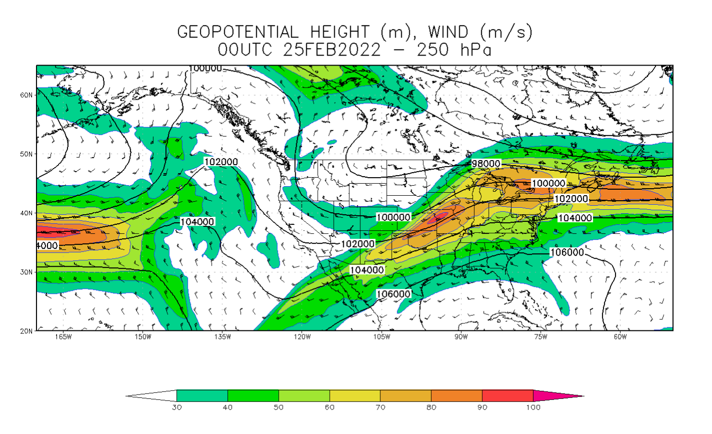	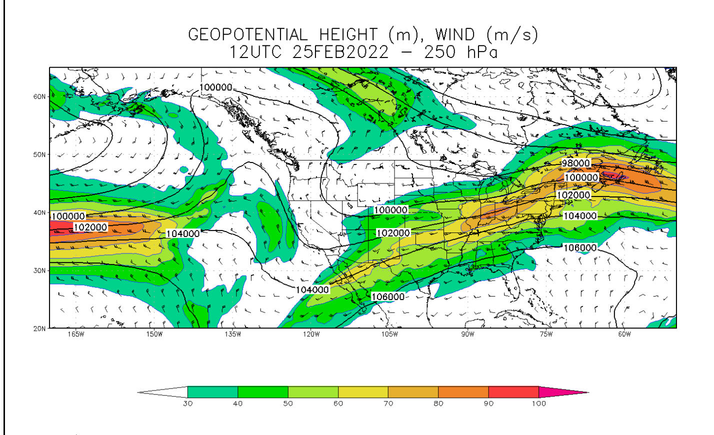
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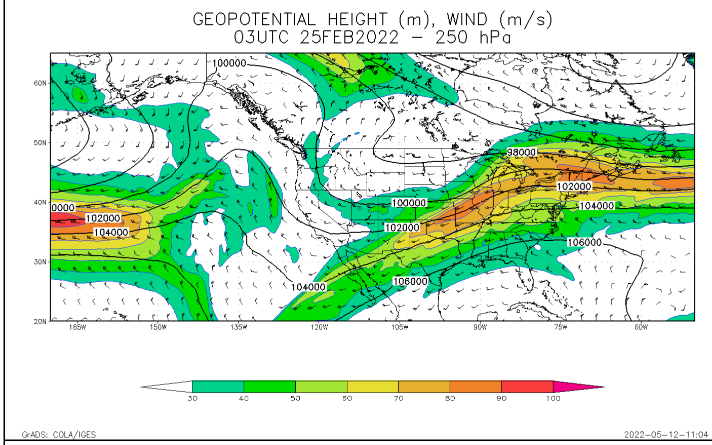	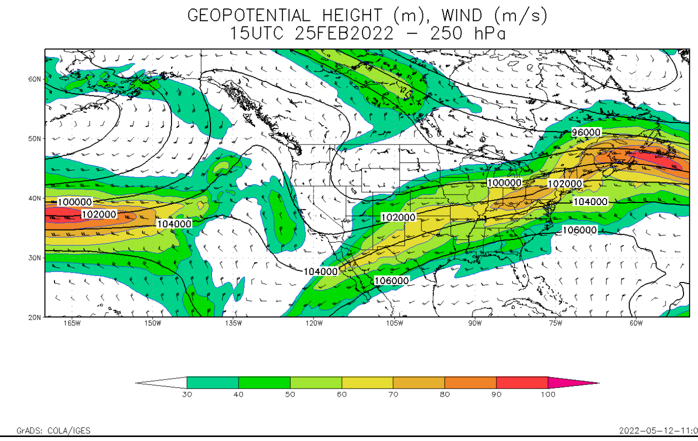
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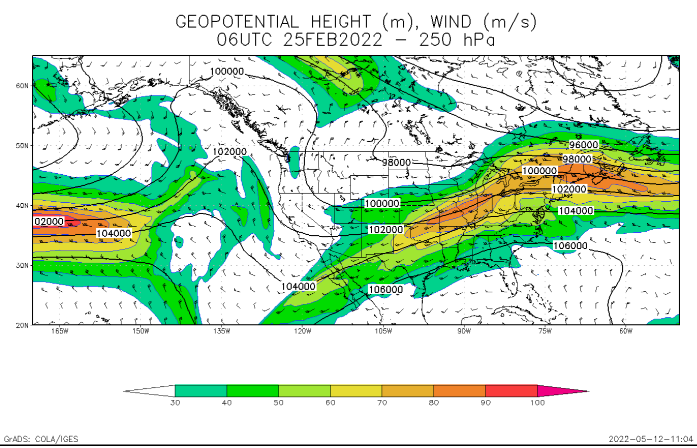	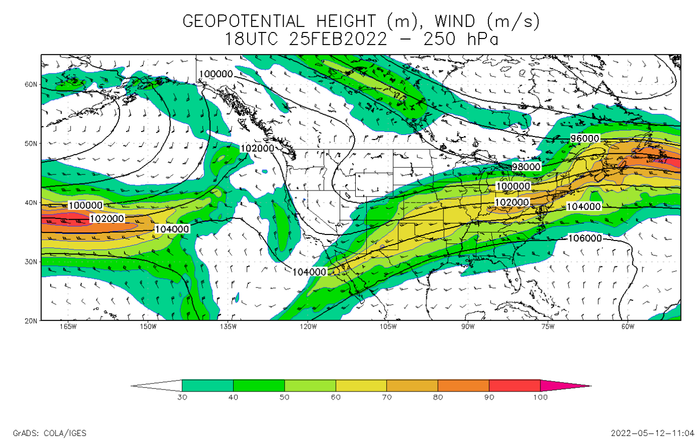
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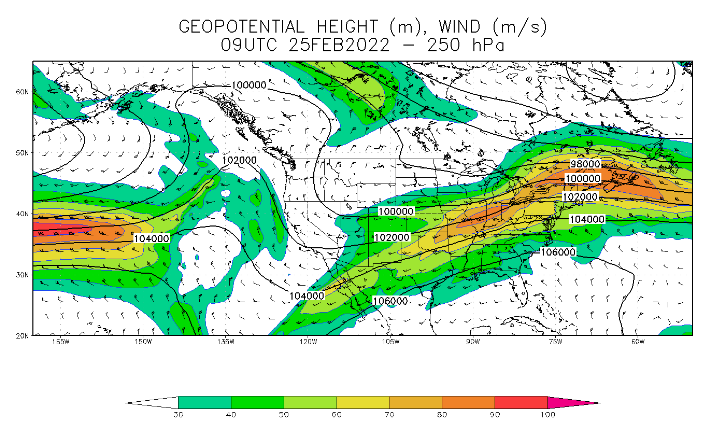	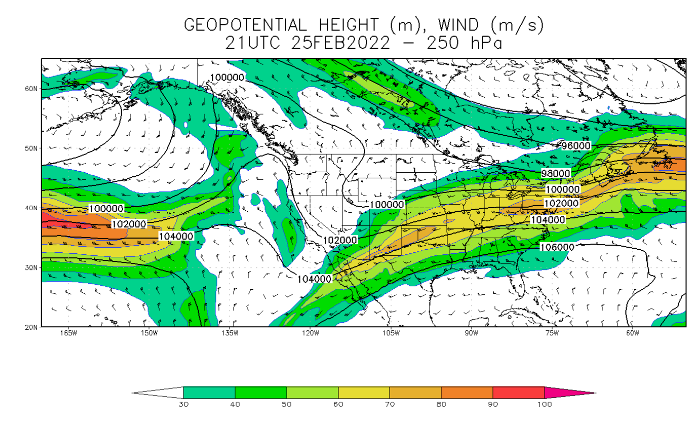

Table 5. 250 hPa Geopotential Height, Sea Level Pressure, and Temperature on 25 February 2022

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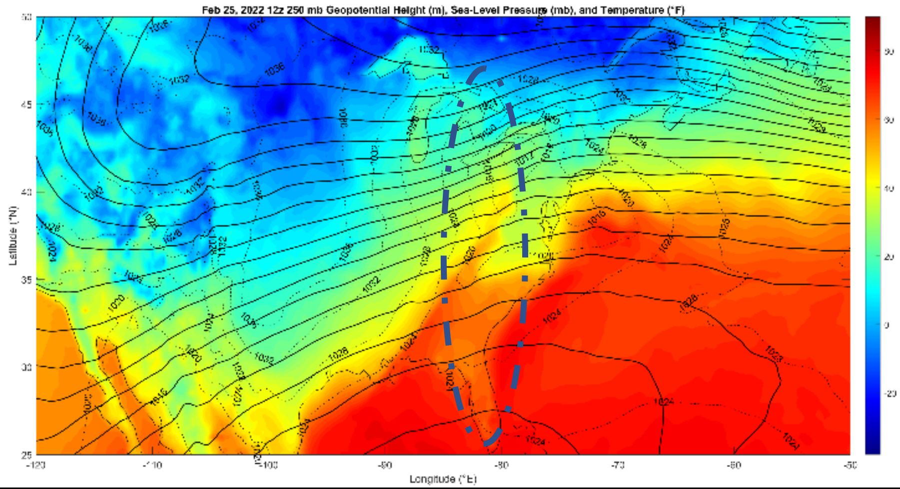
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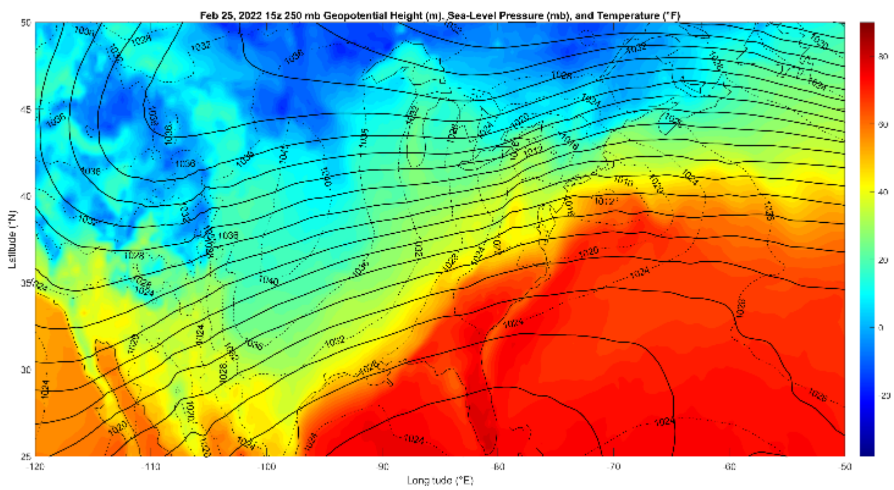
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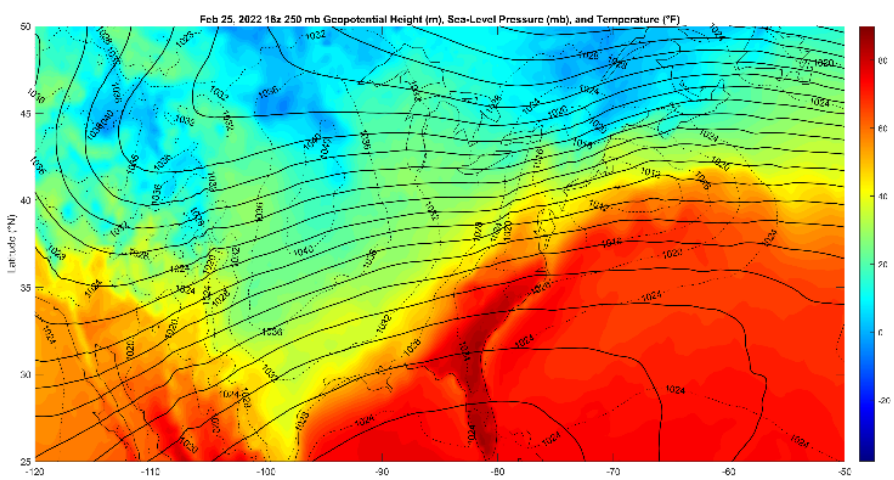

Table 6. 1000 hPa (left) and 850 hPa (right) geopotential heights, temperature and winds on 25 February 2022

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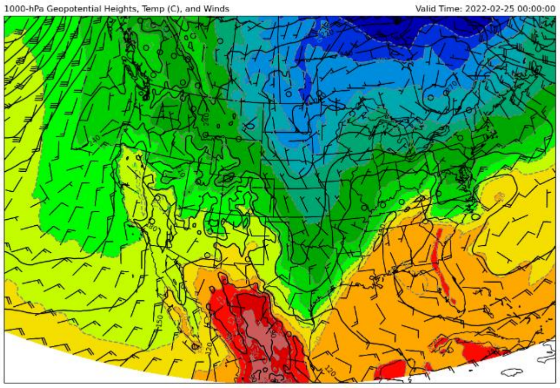
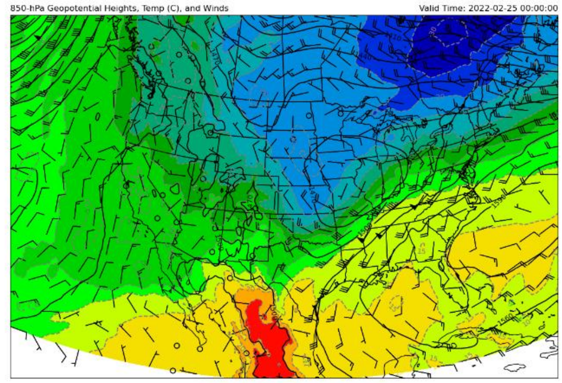
<tr><td></td><td></td></tr>
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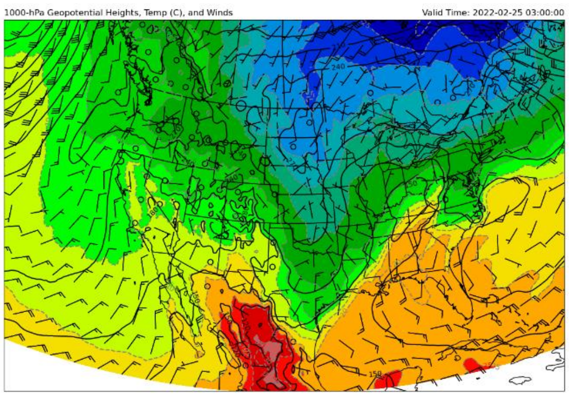
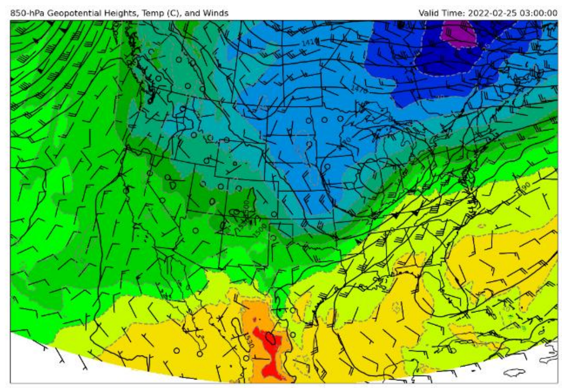
<tr><td></td><td></td></tr>
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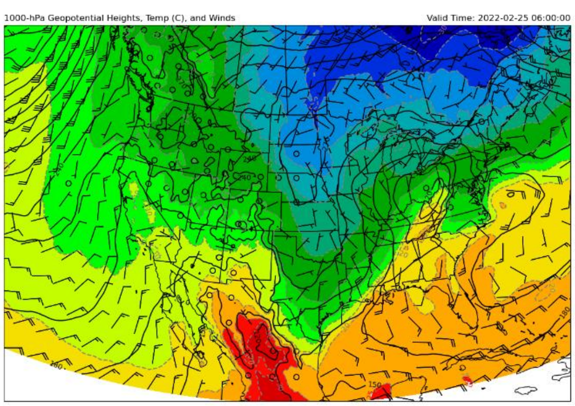
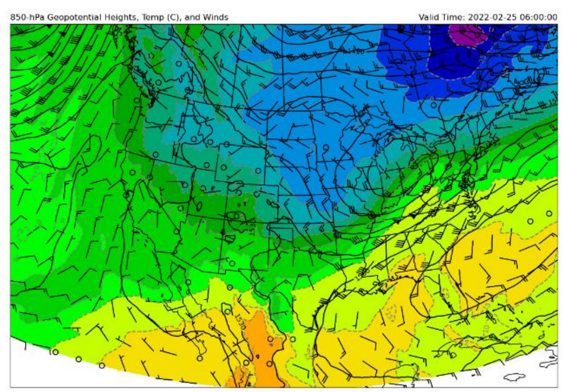
<tr><td></td><td></td></tr>
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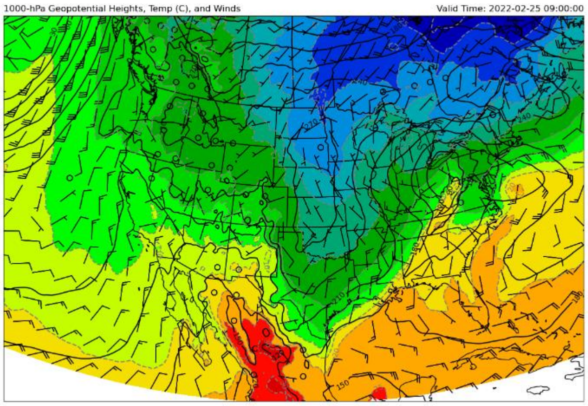
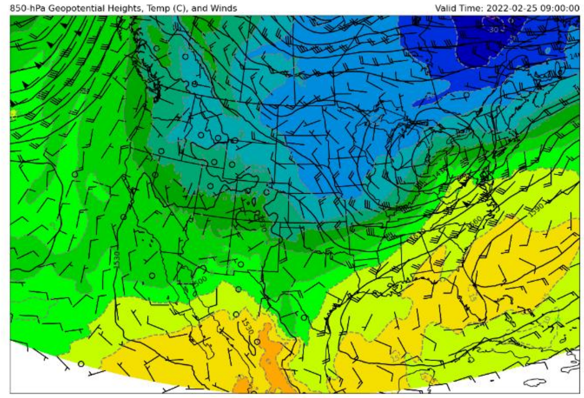
<tr><td>
</td><td>
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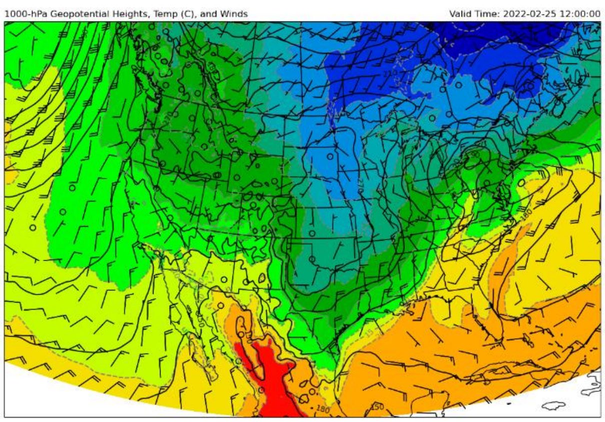
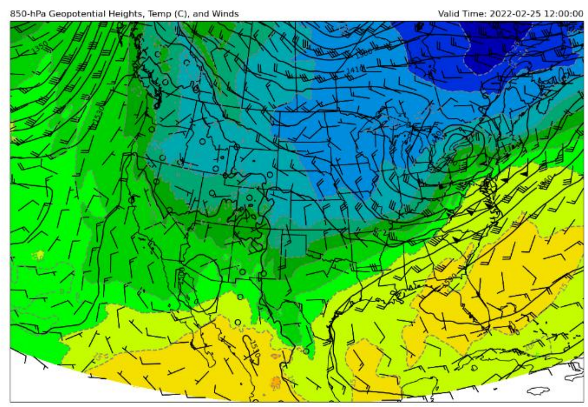
<tr><td>
</td><td>
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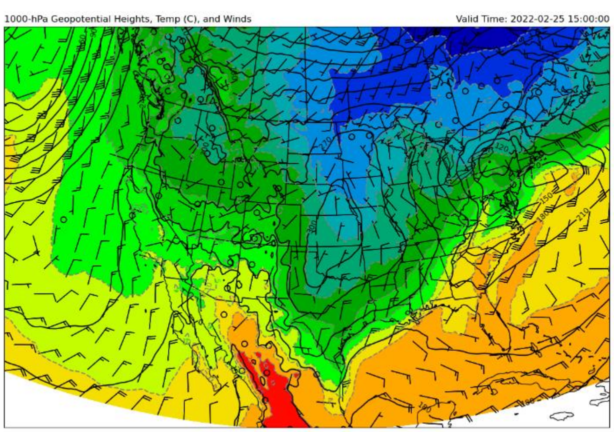
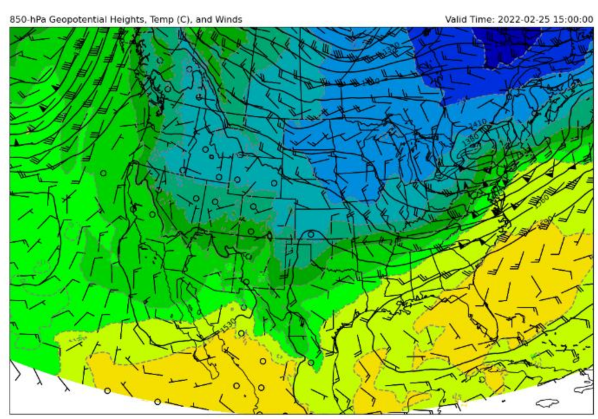
<tr><td>
</td><td>
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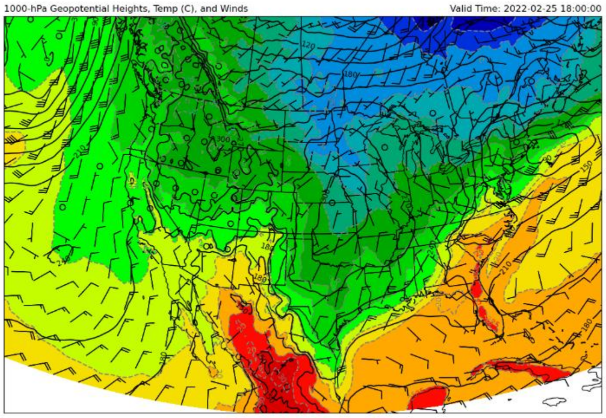
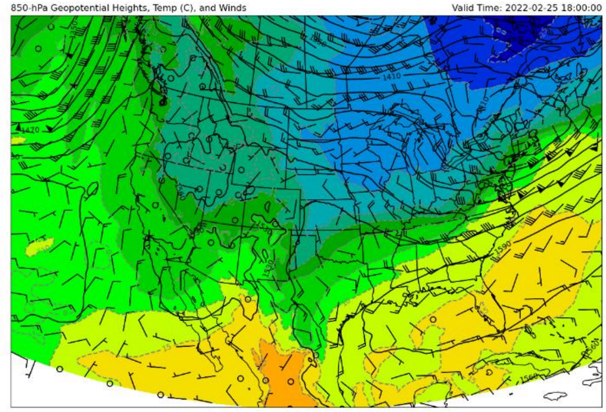
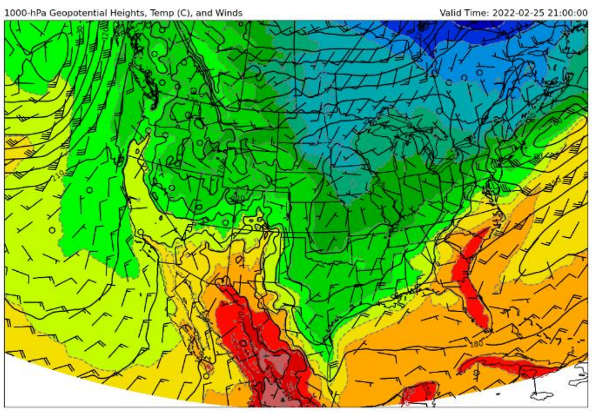
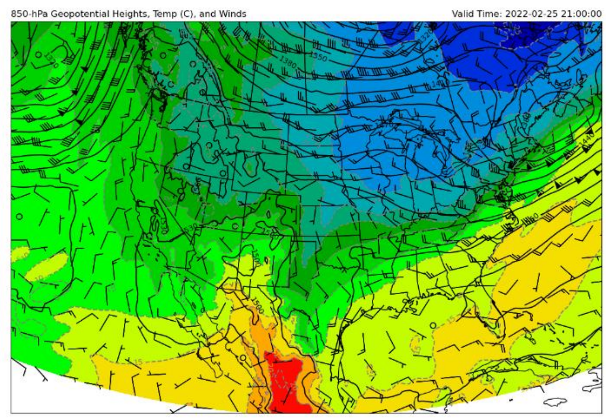
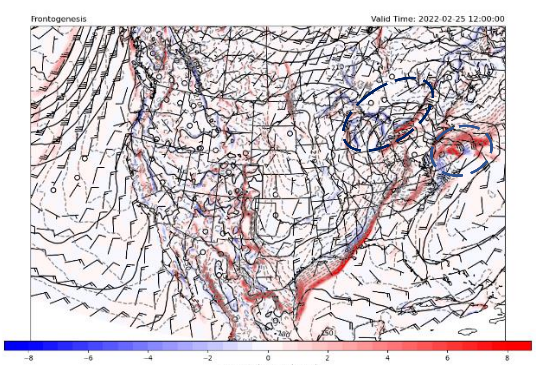
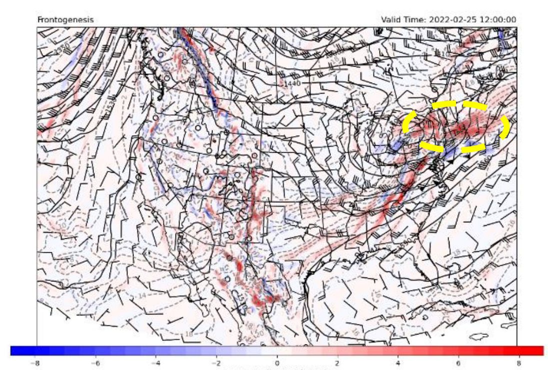
	
21 UTC	21 UTC
	

Table 7. 1000 hPa (left) and 850 hPa (right) frontogenesis on 25 February 2022

12 UTC	12 UTC
	
15 UTC	15 UTC

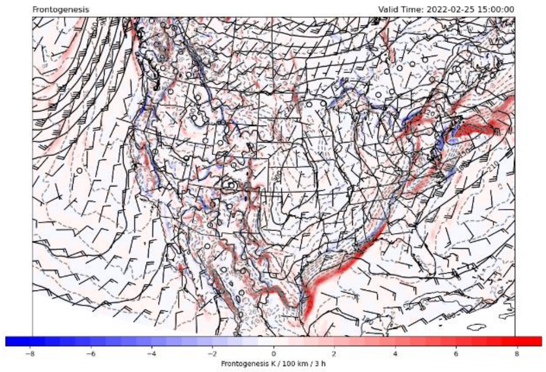
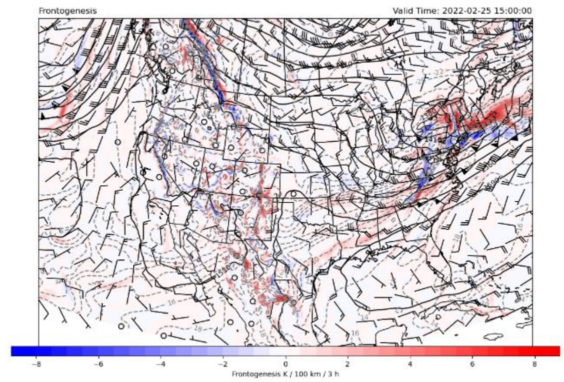
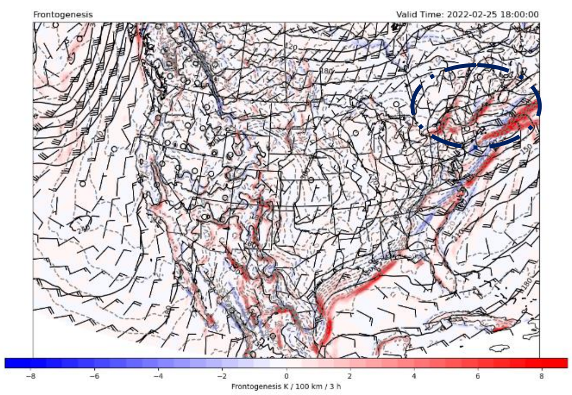
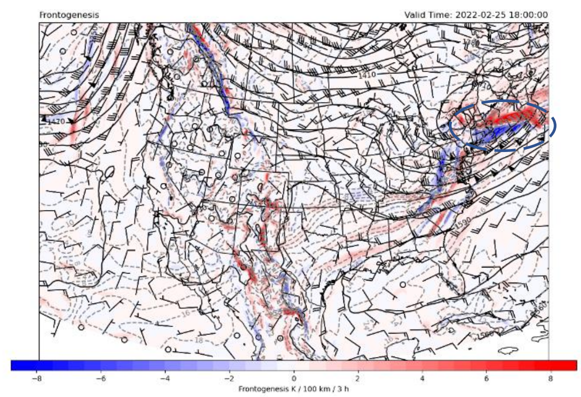
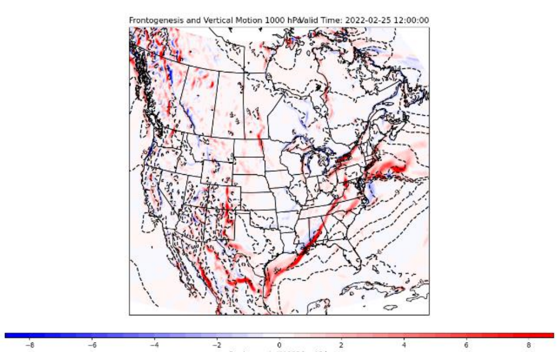
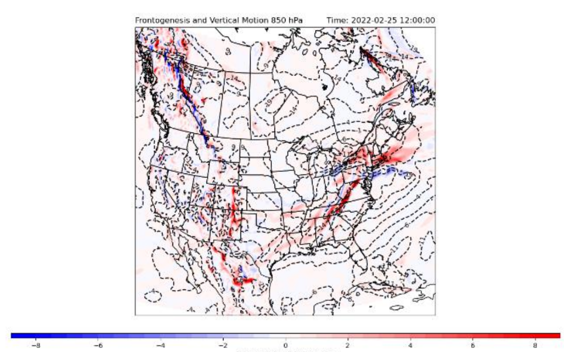
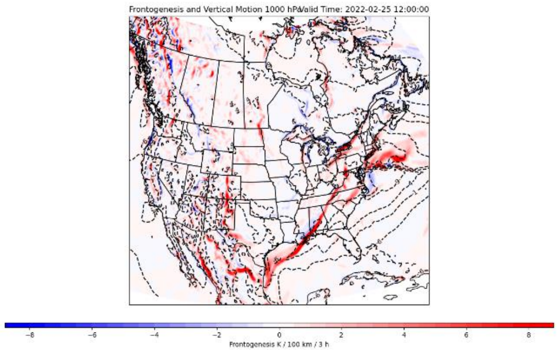
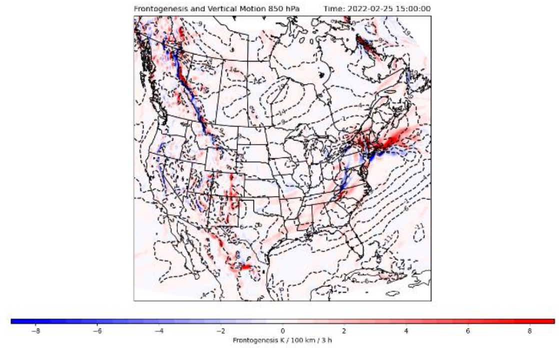
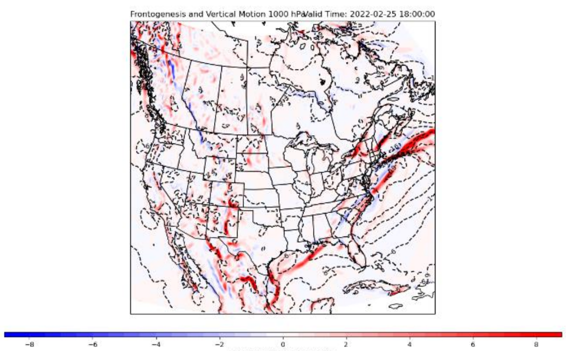
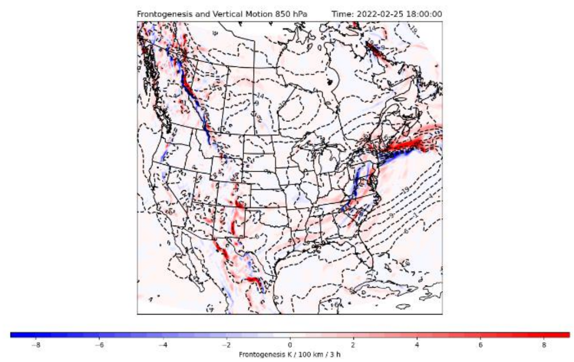
	
18 UTC	18 UTC
	

Table 8. 1000 hPa (left) and 850 hPa (right) frontogenesis overlayed with vertical motions on 25 February 2022

12UTC	12 UTC
	
15 UTC	15 UTC

Frontogenesis and Vertical Motion 1000 hPaValid Time: 2022-02-25 12:00:00 −8 −6 −4 −2 0 2 4 6 8 Frontogenesis K / 100 km / 3 h	Frontogenesis and Vertical Motion 850 hPa Time: 2022-02-25 15:00:00 −8 −6 −4 −2 0 2 4 6 8 Frontogenesis K / 100 km / 3 h
18 UTC	18 UTC
Frontogenesis and Vertical Motion 1000 hPaValid Time: 2022-02-25 18:00:00 −8 −6 −4 −2 0 2 4 6 8 Frontogenesis K / 100 km / 3 h	Frontogenesis and Vertical Motion 850 hPa Time: 2022-02-25 18:00:00 −8 −6 −4 −2 0 2 4 6 8 Frontogenesis K / 100 km / 3 h