A Case Study

Tornado Outbreak in D.C. Area, 7 February 2020

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Introduction

Tornadoes have always been a great source of wonder for me. When I heard the story of the Wizard of Oz as a child, I couldn't believe that "thing" that whisked Dorothy and Toto away to a magical world was real. Of course, I realized later on that real tornadoes don't actually carry people away to different worlds, but the fascination still remained. Growing up in Belgium, I never witnessed any tornadoes and it was never something I considered a real threat, since they were so rare where I lived. And even after I moved to the US, a country which is known to have the most intense and most frequent tornadoes worldwide (Snow, 2020, Global Occurrence section), I never gave much thought to the risk of tornadoes. So when I began my search for an event to research for this Case Study, I was surprised to find out that there had been five tornadoes in the area just a few months ago, and I had had no idea at the time. It made me realize three things: 1. I still had no clue how tornadoes form and how they work, 2. the threat of tornadoes was not as far removed as I thought, and 3. I really need to read the news more often (how on earth had I missed five tornadoes?). I decided that this would be the perfect topic for my Case Study as it was an opportunity to finally understand tornadoes.

On February 7th, 2020, five tornadoes hit the D.C. area between 7:20AM and 8:14AM EST (Hofmann, 2020). These tornadoes were part of a larger event which extended down to the South and lasted over the course of three days: February 5th, 6th and 7th (see Figure 1 for map of the tornado outbreak). For this case study, I will be focusing only on those that occurred in the D.C. area on this particular day. I will also be discussing individual tornadoes in terms of the Enhanced Fujita Scale, a scale which infers wind speeds of a tornado based on the damage it caused. Although it is flawed because different kinds of terrains have a different resilience to tornadoes, it is necessary because we have no way of directly measuring wind speed.

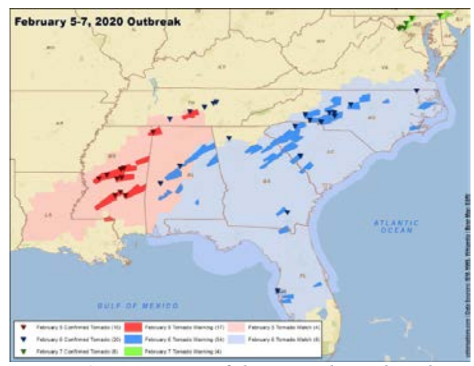

Figure 1: Depiction of the tornado outbreak that occurred in the US from February 5th to February 7th. Retrieved from USTornadoes.com.

The first tornado occurred in Leesburg, Virginia at around 7:20AM to 7:23AM EST. According to the National Weather Service, this tornado was classified as an EF0 and reached an estimated wind speed of 85 MPH. It traveled approximately 3.3 miles at a speed of 60 MPH, as shown in Figure 2. The damage sustained includes uprooted trees, downed tree limbs, roofing damage, and accumulation of debris blown off of people's property. Ultimately, nobody was injured, and the damage was minimal, as is typical of tornadoes of a low EF-scale rating.

Figure 2: Leesburg tornado track. Retrieved from the NWS website.

Figure 3: Dickerson tornado track. Retrieved from the NWS website.

The second tornado occurred in Dickerson, Maryland. It began around 7:28AM and ended about a minute later, at 7:29AM EST. As this tornado only lasted about a minute, it traveled about 1 mile, as shown in Figure 3 to the left. However, it was rated EF1 as it reached winds up to 95 MPH. The damage includes uprooted trees, broken tree limbs, and the most severe being the destruction of several outbuildings, the loss of the roof of a large barn, and a windmill was toppled. Thankfully, there were no injuries or fatalities.

The third tornado hit Boyds, Maryland and lasted from 7:38 AM to 7:39 AM EST. This tornado was rated EF0 on the Enhanced Fujita Scale, and the estimated maximum wind speed was 80 MPH. It traveled about 2.3 miles in about 1 minute. The track of the tornado is shown in Figure 4. Initial damage includes toppled trees which fell and disrupted utility lines. Several structures at a dog training facility were damaged, including a storage building which was flattened and broken off roofing material which was carried by the wind and collided into nearby buildings. There were no fatalities or injuries from this tornado.

Figure 4: Boyds tornado track. Retrieved from the NWS website.

Figure 5: Monrovia tornado track. Retrieved from the NWS website.

The fourth tornado occurred in Monrovia, Maryland. It began around 7:44 AM and ended at 7:50 AM EST. It was rated EF1, with maximum wind speeds of 105 MPH, which is overall the highest speed out of the five tornadoes. It was estimated to have traveled 6 miles, along the track shown in Figure 5. The damage sustained includes uprooted and topped trees, flattened shed and barn, and a silo was damaged. Although some of the toppled trees fell near residence areas, nobody was hurt.

The final tornado occurred near Westminster in Carroll County, Maryland. It lasted from approximately 8:03 AM to 8:14 AM EST. This EF1 tornado lasted the longest out of the five, and therefore traveled the farthest – about 10.3 miles (see Figure 6 for the track). It caused damage to trees, both snapped and uprooted, which in turn damaged several cars, roads, and homes. It also caused roofing damage, fencing damage, and multiple vehicles were blown over. Again, there were no injuries or fatalities.

Figure 6: Westminster tornado track. Retrieved from the NWS website.

Upon further research, it seems that this tornado outbreak was unusual in location and time of year. According to meteorologist Chuck Bell, the February 7th tornado warning was the earliest ever issued in this area (Bonk &

Ortiz, 2020, Damage section). Winter tornado events are usually sparse, in fact, the Washington Post states that "previously, the Washington region had seen a maximum of just one tornado in any winter severe thunderstorm event" (Livingston, 2020). Not only is it atypical to see tornadoes in the D.C. area this early in the year, but it's also highly unusual for there to be so many. So what caused this rare outbreak of winter tornadoes?

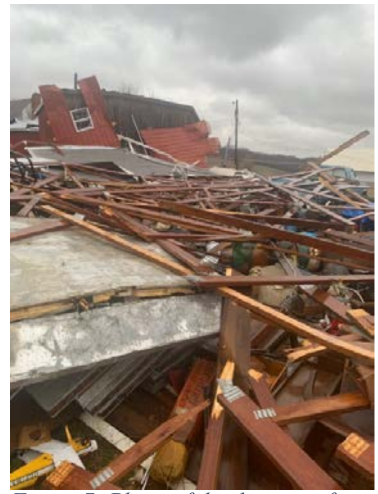

Figure 7: Photo of the damage of Burall farm in Monrovia, Maryland. Taken by Amanda Warner. Retrieved from NBCWashington.com.

Background

Topography

First, let's take a look at the topography and relative location of the area. This can be very influential when it comes to active weather, as certain topographic features can serve as barriers while others can help further support to occurrence of active weather.

Maryland is located between several important topographic features which influence active weather. First, it is located to the west of the Atlantic Ocean, which serves as a source of cool humid air masses which we call maritime polar (mP) air masses. Next, it is located north of the Gulf of Mexico, from which large masses of warm, humid air known as maritime tropical (mT) air masses blow in. This particular kind of air mass often contributes to active weather as the humidity is potential energy. And finally, Maryland is located east of the Appalachian Mountains, which can serve as a barrier to the warm, dry air that is the continental tropical (cT) air mass which comes in from the west.

Figure 8: Terrain map of Maryland and part of Virginia. Including the locations of the tornadoes (1) Leesburg, (2) Dickerson, (3) Boyds, (4) Monrovia, (5) Westminster, and (IAD) Dulles International Airport weather station. Retrieved from Google Maps, terrain mode.

Pictured above is an approximate representation of the locations of all 5 tornadoes, as well as the location of IAD, the nearest airport from which we will be using the soundings. The airport is part of the Automated Surface Observing System (ASOS), which provides hourly weather data and measurements that are uploaded to an online database and made available to everyone.
Weather Conditions

Next, let's take a look at the surface weather conditions at 12Z (1200 UTC) on February 7th, approximately 20 minutes before the first tornado formed (see Figure 9).

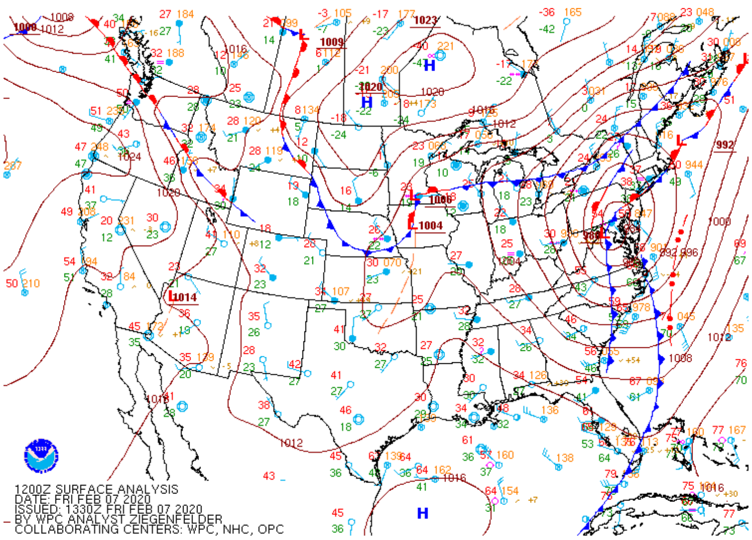

Figure 9: Surface analysis at 12Z, on 7 Feb 2020. Retrieved from WPC Surface Analysis Archive.

There is a very strong center of low pressure above Maryland, with closely spaced contour lines indicating a steep pressure gradient. Additionally, the pressure at the center is shown to be 980-mb, which is quite low. For comparison, all other surface lows in the United States at this time were 1000-mb and above. Notice also the presence of multiple fronts in the area, specifically the cold front hovering above, if not slightly to the west of the location at this time. The cold front is a mass of continental polar (cP) air moving in and undercutting the maritime tropical (mT) air mass. As the warm, humid air is forced aloft, the process of (W)RECHCR begins. During this process, the warm air rises, expands and then cools adiabatically. This cooling causes the air to humidify and eventually once the air has reached saturation (i.e. a relative humidity of 100%) it begins to condense. This means that clouds form and active weather begins. Additionally, because condensation is a heat liberating process, it releases energy which contributes to intensifying active weather.

Other factors contributing to the rise in warm air that are present on the surface map above are closely spaced contour lines which indicate surface wind convergence. This encourages counterclockwise, inward, and upward cyclonic flow. The surface streamline map (see Figure 10, to the right) further demonstrates the convergence of winds which encourage active weather.

What other factors contributing to the severe weather that occurred can be seen in upper air maps? Let’s take a look.

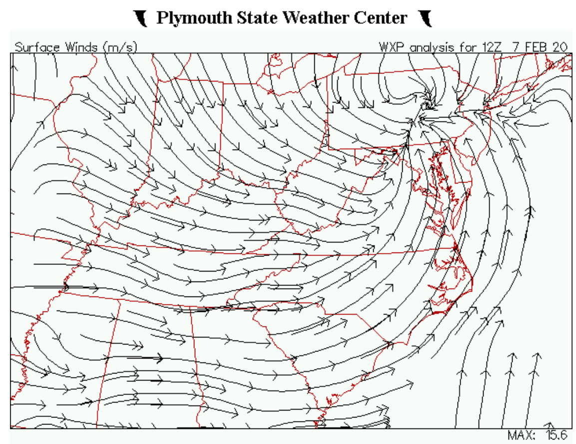

Figure 10: Surface wind streamlines at 12Z, on 7 Feb 2020. Retrieved from Plymouth State Weather Center Surface Map Archive.

Analysis

First, let’s look into the formation of supercell storms. Less than 50% of supercells end up forming tornadoes but are responsible for the creations of most tornadoes (Herman, Lutgens, & Tarbuck, 2018, p.262). Like most thunderstorms, these cells form when (W)RECHCR occurs in unstable atmospheric conditions. They tend to form along cold fronts, which we saw previously on the surface analysis map (see Figure 9). However, these thunderstorms are different in that they form in conditions where there is wind velocity and direction shear, meaning the speed and direction of the winds at the surface must be different than those aloft. According to the surface wind speed map (see Figure 11), the winds were 7m/s (approximately 14 knots) around the area of interest.

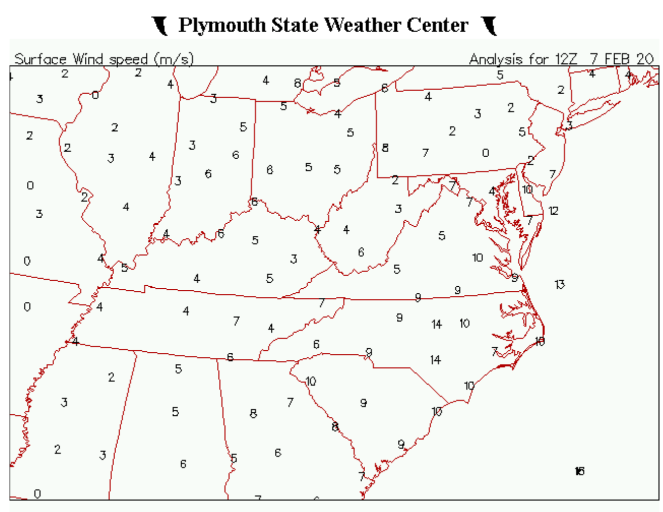

Figure 11: Surface wind speed at 12Z, on 7 Feb 2020. Retrieved from Plymouth State Weather Center Surface Map Archive.

However, looking at the 250-millibar (mb) upper level map (see Figure 12, next page), the winds above this same location reach up to 195 knots. This is an impressive velocity shear of 181 knots. This can be attributed to the jet streak, which is an area of diverging winds and therefore an area of high velocity winds aloft within a jet stream.

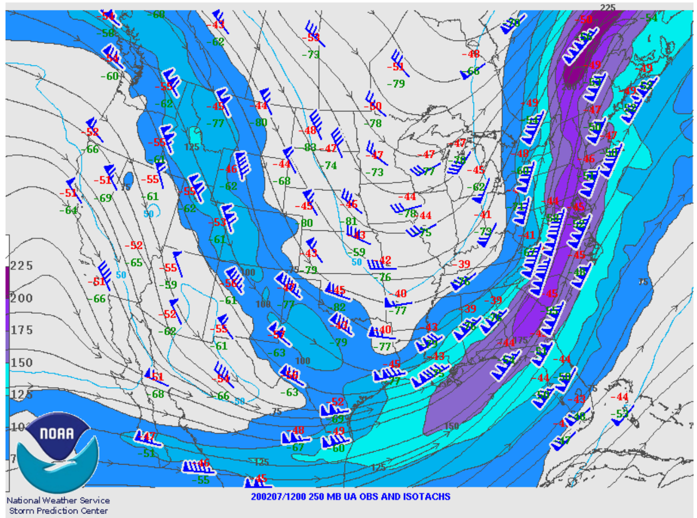

Figure 12: 250-mb map at 12Z, on 7 Feb 2020. Retrieved from NOAA Surface and Upper Air Map Archive.

Because of the shear, the upper part of the cell is blown into the form of an anvil, which is carried further downstream than the lower portion of the cell due to strong upper level winds and slower surface level winds. The tilt within the storm causes a separation of the downdraft and updraft systems, therefore reducing the risk of precipitation falling into the updraft and causing the storm to diminish. This allows the storm to stay active much longer periods of time, sometimes exceeding a 12-hour lifespan.

Tornadoes also form when there is a strong velocity and directional wind shear. When this is the case, the difference in speed and direction causes a spiral pattern in the air movement, and eventually a vortex tube forms. As we have seen above, there are indeed both velocity and directional shear. However, we can further verify this by looking at the Stüve sounding from IAD (see Figure 13 above). As expected, the sounding indicates the presence of a great velocity shear, as shown by the drastic increase in feathers on the wind arrows to the right of the graph. It also shows the directional shear: the arrows start at NW at 200-mb, then rotate in a counterclockwise spiral with decreasing altitude, ending at S/SE at the surface.

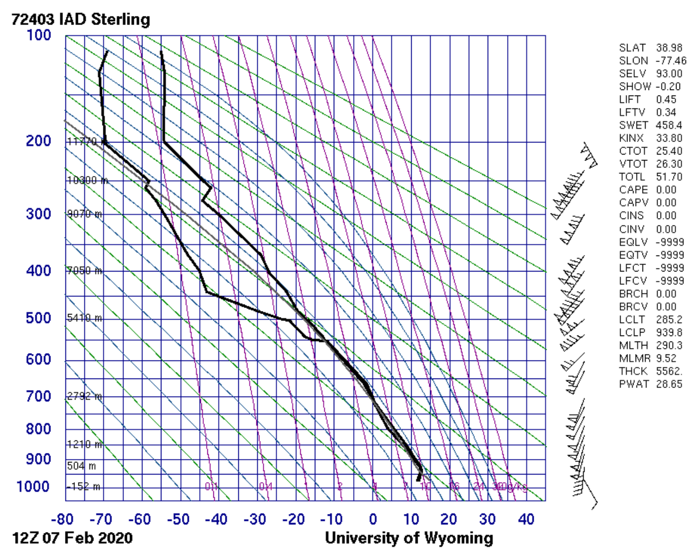

Figure 13: Stüve sounding from IAD at 12Z, on 7 Feb 2020. Retrieved from University of Wyoming Sounding Archive.

Now that we have confirmed wind shear and the likely formation of the supercell and vortex tube, we can move on to the next steps of the tornado formation. Once the vortex tunnel has formed, it will only go on to become a tornado if it gets picked up by the supercell updraft. The vortex then stands up vertically and stretches out within the supercell and eventually causes the entire storm cell to rotate in a counterclockwise motion, becoming a mesocyclone. This in turn produces a funnel cloud which spins down from the bottom of the cloud to the surface. Only when it touches down does it become a tornado.

Now that we know how and why it formed, let's evaluate the factors that influenced the intensity of the storm and tornado outbreak. Looking at the radar map of the area at 1215Z (see Figure 14) we can see where the most intense weather is. Unfortunately, I was not able to find the hook echo, however, this map can still be useful. Using this, we can evaluate the overlap of other factors and the most intense areas of the storm.

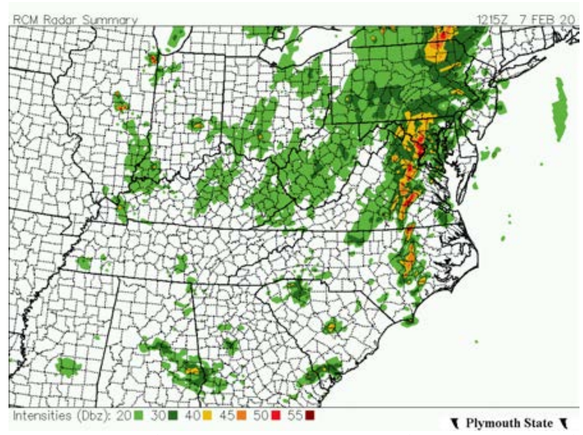

Figure 14: Radar map at 1215Z, on 7 Feb 2020. Retrieved from Plymouth State Weather Center Radar Archive.

An important factor in all active weather is the presence of moisture. In fact, condensation is the second most important energy source of active weather (the first being the sun). According to the water vapor satellite image above (Figure 15), the areas which experienced the most intense weather are also the areas receiving the most moisture. This large amount of moisture is most likely the result of an atmospheric river carrying humid air from the Gulf of Mexico. The added energy from the moisture can serve to greatly intensity existing weather.

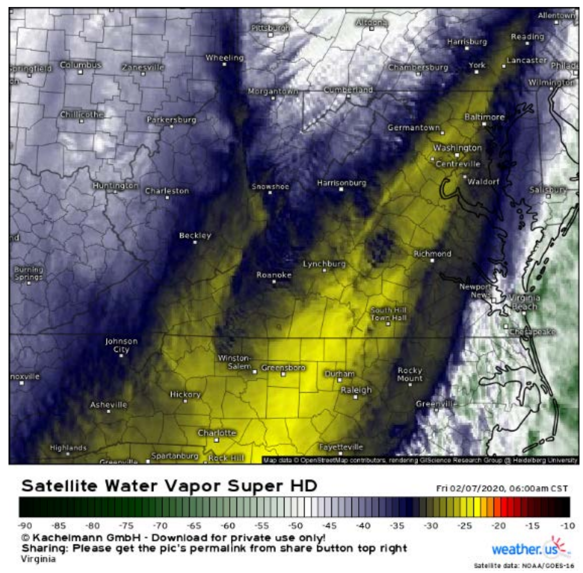

Figure 15: Water vapor satellite image at 12Z, on 7 Feb 2020. Retrieved from Weather.us.

Additionally, let's take a look at the Infrared satellite image of this area at 0910Z, about 3 hours before the event (see Figure 16). Notice the white areas above Maryland. These are likely cloud tops, which show up as bright white on the infrared image when they are higher up in the atmosphere. Typically, these are cumulonimbus clouds as they reach up to the tropopause. As these are formed in unstable air conditions, the presence of these white cloud tops indicate instability, which is ideal for severe weather. In fact, the cloud tops we are seeing here likely belong to the supercell storms, which form massive cumulonimbus clouds. Although it is still three hours before the event occurred, these storm cells can last a very long time before dissipating.

Figure 16: Infrared satellite image at 0910Z, on 7 Feb 2020. Circled in red is the approximate location of the event. Retrieved from Plymouth State Weather Center Archived Satellite Images.

Factor Evaluation: The "Terrible Ten"

In order to further evaluate this event, I'm going to be looking at which "Terrible Ten" factors were present at the time (Krayer and Prater). This checklist of ten factors is generally used to predict whether severe weather will occur in a certain area. We already know that severe weather occurs, but it may reveal additional factors that may have contributed to this event. Let's begin:

1. Will there be a weather front near the location of the event? Yes, according to the surface map at 12Z, approximately 20 minutes before the first tornado. There are multiple fronts in the area, including two cold fronts and two occluded fronts (see Figure 17).

2. Is the weather front sharp enough to produce a difference in temperature and/or dew point of 15°F? Yes, there is a 15°F difference in temperature. The surface temperature map below reveals that temperatures in areas where the cold front has passed range from 30°F to 35°F, with some even dipping into the 20's. Meanwhile, the areas that have not been overtaken by the cold front have temperature ranging from 57°F to 67°F. A sharp weather front indicates that it is moving rapidly.

3. Is the expected time of severe weather during the afternoon or early evening? The tornadoes occurred during the early morning, so no.

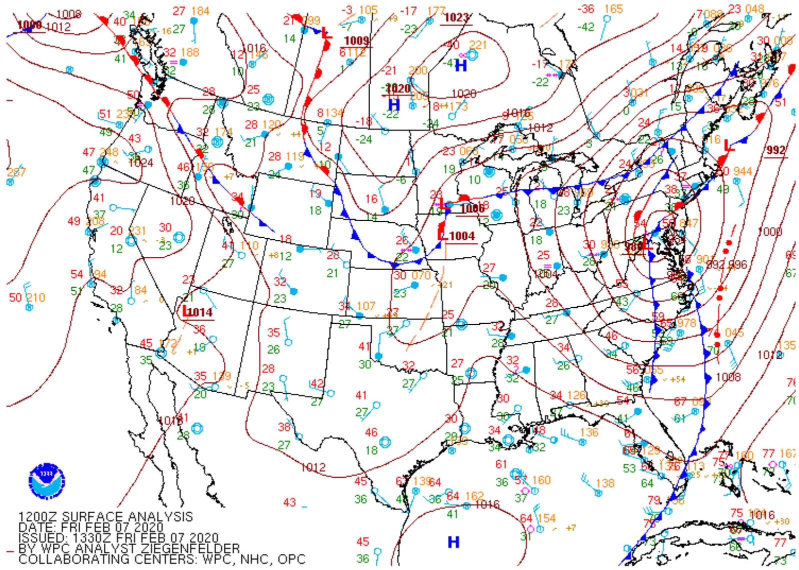

Figure 17: Surface analysis at 12Z, on 7 Feb 2020. Retrieved from WPC Surface Analysis Archive.

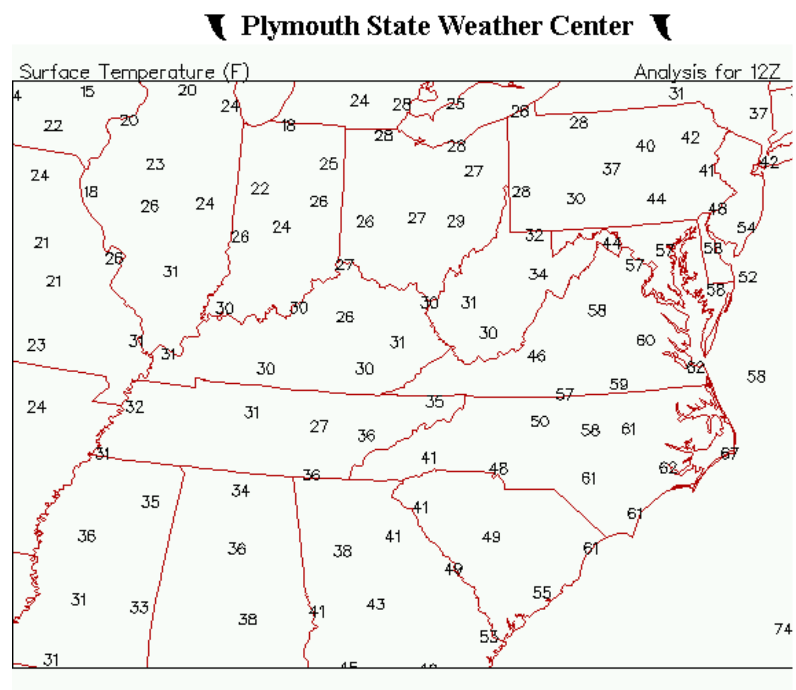

Figure 18: Surface temperature map at 12Z, on 7 Feb 2020. Retrieved from Plymouth State Weather Center Surface Map Archive.

4. Are the dew points at the location high (above 50 in the winter)? Yes, the dew point is 55°F, as shown circled in green on the surface dew point map below at 12Z.

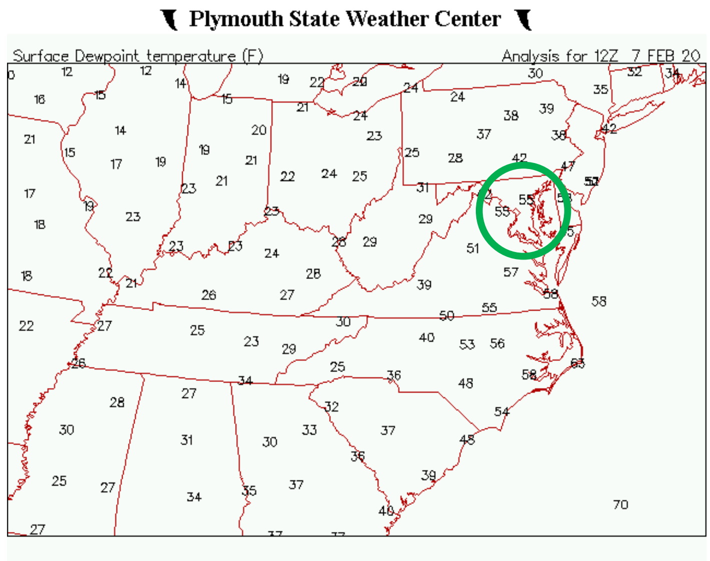

Figure 19: Surface dew point temperatures at 12Z on Feb 7, 2020. Retrieved from Plymouth State Weather Center Surface Map Archive.

5. Are the winds from a water source at a speed of 30 knots or greater at the 850-mb level?
Yes. The winds coming from the south reach up to 60 knots above the region of interest. This low-level jet bringing moisture from the Gulf of Mexico is a significant contributor to active weather.

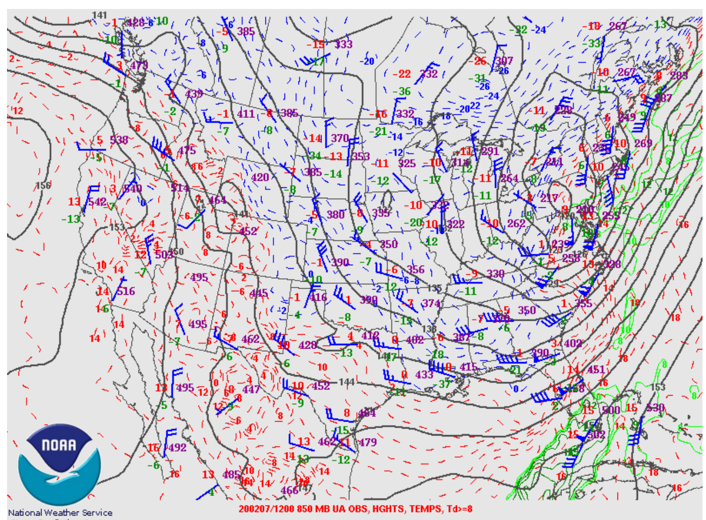

Figure 20: 850-mb map at 12Z on Feb 7, 2020. Retrieved from NOAA Surface and Upper Air Map Archive.

6. Is there a strong long wave or short-wave trough west of the location at the 700 and 500-mb levels? Yes, there is a long wave trough west of Maryland on the 500 and 700-mb maps (see Figure 21, next page). The contour lines are packed very close together, so this long wave trough is fairly strong. This kind of wave generally controls the track of the storm. Additionally, there is a very subtle short-wave trough on the 700-mb map, which contributes greatly to intensifying active weather.

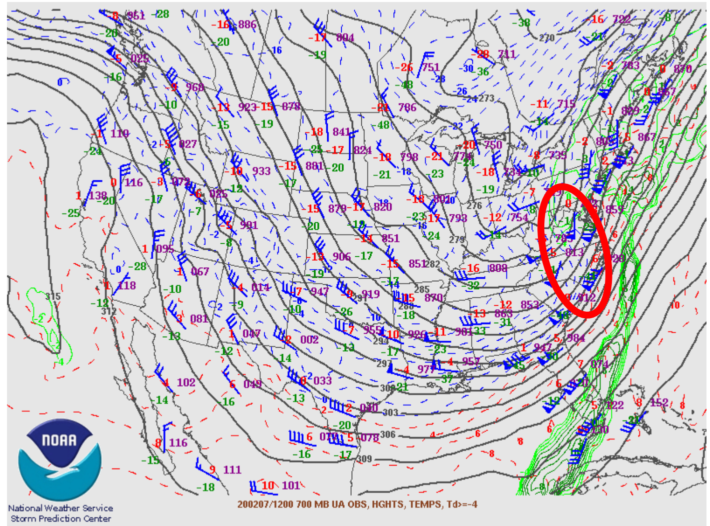

Figure 21: 700-mb map at 12Z on Feb 7, 2020. Circled in red is subtle short wave trough. Retrieved from NOAA Surface and Upper Air Map

7. Will the location be below a jet streak at the 300/250-mb level? Yes, although it is not located below the right entrance or left exit region, it is located beneath the core of the jet streak (see Figure 23, next page). This particular jet streak is unusually strong, especially for winter. In the words of Professor Krayer, it's a "rip-roaring jet streak for any season, let alone the dead of winter." Looking at the 250-mb map, there are particularly strong winds within the core, reaching up to 195 knots.

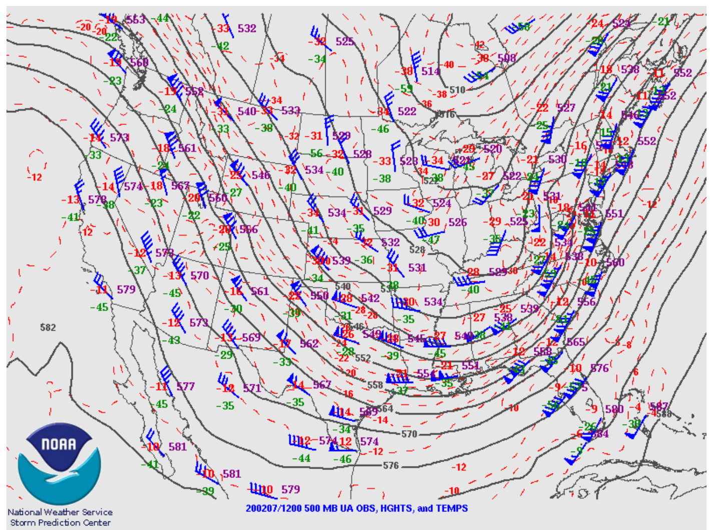

Figure 22: 500-mb map at 12Z, 7 Feb 2020. Retrieved from NOAA Surface and Upper Air Map Archive.

8. Are the winds at the 300/250-mb level diverging around and to the west of the location? Yes, the yellow contour lines on the 300-mb map indicate divergence aloft around and to the west of the D.C. area. Net divergence aloft encourages the cyclonic inward and upward motion of air which leads to active weather. Therefore, very intense divergence will lead to intense severe weather.

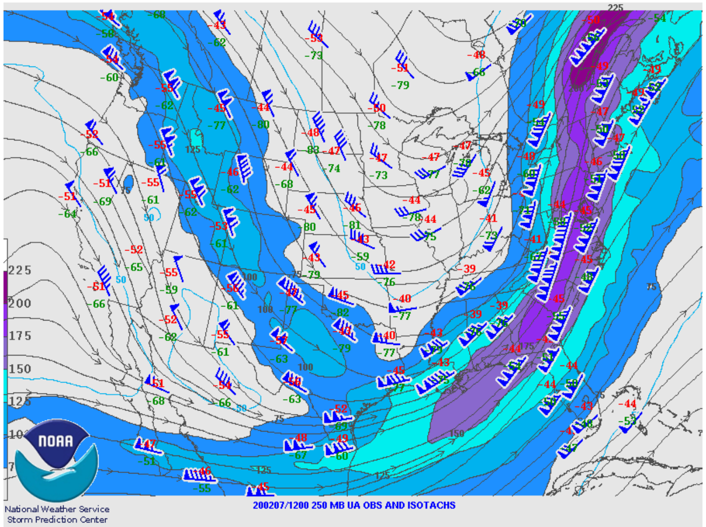

Figure 23: 250-mb map at 12Z on 7 Feb 2020. Retrieved from NOAA Surface and Upper Air Map Archive.

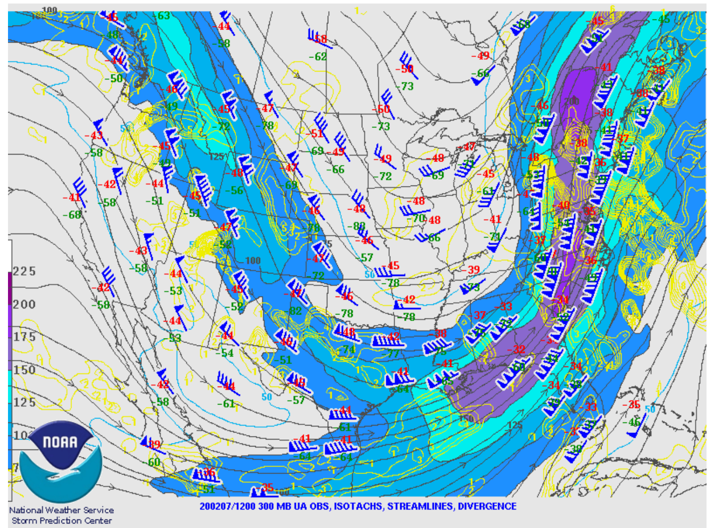

Figure 22: 300-mb map at 12Z, on 7 Feb 2020. Retrieved from NOAA Surface and Upper Air Map Archive.

9. On the Stüve sounding, does the wind direction change in a counterclockwise spiral with decreasing altitude? Yes, there is a counterclockwise change in the wind direction. The wind is SW for the majority, starting at NW and slightly changing to S as it reaches the surface.

10. On the Stüve sounding, is the Lifted Index (LIFT) < 0 and/or the Totals Index (TOTL) > 50? As shown in the Stüve sounding above, the LIFT is not < 0, although it is very close, and the TOTL is slightly greater than 50 at 51.70. This indicates an unstable atmosphere, which is ideal for severe weather.

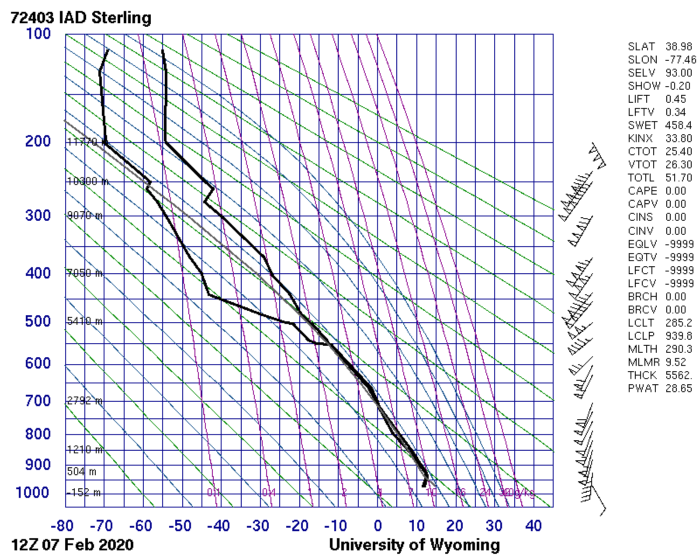

Figure 21: Stüve sounding at IAD at 12Z, on 7 Feb 2020. Retrieved from University of Wyoming Sounding Archive.

In total, this weather event receives a 9 out of 10. Although it's 1 point away from being a perfect 10, it's still indicative of a region of severe weather. Overall, this checklist has confirmed that multiple factors contributing to or demonstrating that there were very unstable atmospheric conditions around the D.C. area were ultimately responsible for the severe weather event which resulted in 5 tornadoes.

Going Global

Although we now understand the factors which caused and intensified this weather event, we still don't know how and why this occurred at such an unusual time of the year. As I previously mentioned, tornadoes typically occur during the spring or summer in the Mid-

Atlantic, rather than in the dead of winter. According to the Storm Prediction Center, the Mid-Atlantic has experienced a whopping 25 winter tornadoes in the past decade. As you can see in Figure 26, the highest number of tornadoes in a decade was previously 11, which happened in the 1960s. So what is causing this sudden increase in winter tornadoes in the Mid-Atlantic?

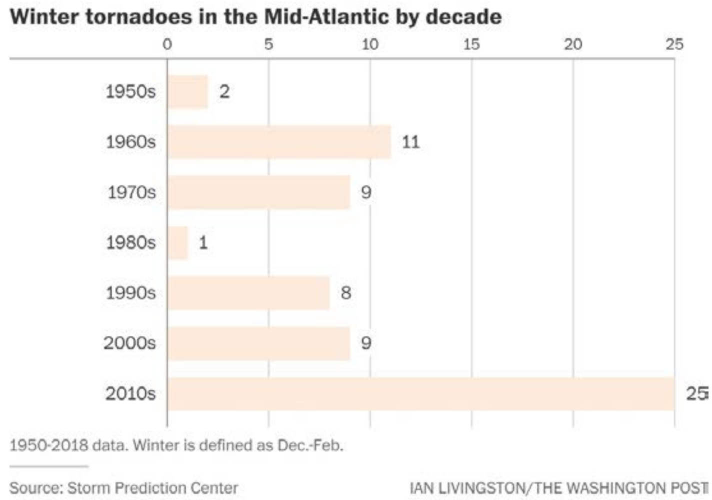

Figure 24: Chart portraying the number of tornadoes occurring in the Mid-Atlantic in winter, sorted by decade. Retrieved from WashingtonPost.com

According to NOAA, the average February temperature this year in the US was 2.4°F above average, ranking among the warmest 1/3 period of the 126-year period of temperature record (National Climate Report: February 2020, February temperature section). The reason behind this may lie in the patterns of global oscillations. At the time of the event, in early February, the North Atlantic Oscillation was in its positive phase. Strong positive phases of this particular oscillation are generally associated with increased temperatures in the eastern United States, and with changes in intensity of jet streaks (North Atlantic Oscillation, n.d.). Therefore, the NAO+ would justify both the higher temperatures and unusually powerful jet streak that are responsible for this event.

Ranking the Causes

I believe that the most important factor in causing this tornado outbreak was the wind velocity and wind direction shear. The velocity shear is significant, and the directional shear encouraged a counterclockwise, cyclonic spin. Specifically, the strength of the shear can be attributed to the surprisingly strong jet streak at 250/300-mb. Without the shear, neither the supercell nor the vortex tube would have been able to form – both of which are absolutely necessary in order for tornadoes to occur.

The second most important factor in this event was the presence of moisture. As shown in the water vapor satellite image, a significant amount of moisture is being carried in by an atmospheric river from the Gulf of Mexico. There is an additional low-level jet supplying moisture to the area, as shown by the 850-mb map. The effect of the added moisture can be seen in the high dew points around the location, which was 55°F during the tornado outbreak. This moisture will have served to feed the supercell storms that were carrying the tornadoes, causing the surprising number of individual tornadoes.

And finally, the third most important factor is the strong positive phase of the North Atlantic Oscillation. The formation of the tornadoes would not have been possible without the right weather conditions, which were brought about by NAO+. However, I am ranking this third because it is impossible to fully confirm that the unusual conditions can be attributed to this global oscillation. There are other possibilities, such as climate change.

Conclusion

Overall, I found this case study both very interesting and a challenge. As I mentioned in my Introduction, I had little prior knowledge about tornadoes. I found this a very interesting way to learn about them, as I was immediately applying what I had learned in the lecture to a real-life situation. It was challenging for the very same reason. I had to use multiple resources, including YouTube videos, the textbook, the slides, and the lecture videos in order to fully understand the process. It was also challenging in that there are so many different aspects to this single weather event. At times it was hard to wrap my mind around everything and understand how each factor relates to one another. However, I feel that I now understand how tornadoes form and how they work in a more three-dimensional way.

The most interesting part of this case study was looking into the reason for this unusual occurrence. It's easy to just focus on local weather when analysis an event, however, I think it's just as important to take a step back and compare it to global patterns, such as oscillations. This was particularly interesting because when I first chose this event, I didn't realize it was unusual, but after a bit of research I realized it was quite a special case.

I believe that overall, the data collected was accurate and reliable. I retrieved all maps and soundings from trustworthy weather websites that were recommended. However, I did notice that the Convective Available Potential Energy (CAPE) was not measured in the Stüve sounding. This would have been helpful in order to confirm the existence of potential energy from water vapor in the air. Additionally, the infrared satellite image did not provide a good close up of Maryland and was not a high enough resolution to crop it down.

In order to further study this event, I believe it would be useful to have access to maps which show the hook echo of the tornado. In order to do that, we must use storm-relative velocity radar maps. These show when winds are moving away or towards the Doppler radar, and therefore allows us to make inferences as to where the tornado is in the supercell based on counterclockwise movement. I would also like to compare the effects of NAO+ on the Mid-Atlantic area with other affected areas, such as North Europe and the Mediterranean, to ensure that it is responsible for the unusual weather.

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